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Issued May 31, 1910.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ANIMAL INDUSTRY.—BULLETIN 122.
A. D. MELVIN, CHIEF OF BUREAU.

FACTORS CONTROLLING THE MOISTURE CONTENT OF CHEESE CURDS.

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WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1910.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., February 15, 1910.

Sir: I have the honor to transmit, and to recommend for publication in the bulletin series of this Bureau, the accompanying manuscript entitled "Factors Controlling the Moisture Content of Cheese Curds," by J. L. Sammis, of the Wisconsin Agricultural Experiment Station, and S. K. Suzuki and F. W. Laabs, of the Dairy Division of this Bureau, this being a report of a part of the cooperative investigations in cheese making which are in progress at the Wisconsin Experiment Station between that Station and this Bureau.

The problem of controlling the moisture content of cheese curds in the vat is one of much importance to the modern cheese maker, and the methods used in the experiments reported in this paper were specially planned to meet practical conditions. It is hoped that the results and conclusions will be of value to the cheese-making industry as well as to teachers and students in this line of work.

Respectfully,

A. D. Melvin,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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FACTORS CONTROLLING THE MOISTURE CONTENT OF CHEESE CURDS.

INTRODUCTION.

In the cheese-making industry some practically exact methods of measuring the conditions have already come into general use. The thermometer has replaced the hand as an instrument for measuring temperature; the rennet tests devised by Marschall, Monrad, and Harris have replaced the senses of taste and smell as means for measuring acidity of milk in the cheese vat; and the standard alkaline solution for measuring acidity is coming into general use among careful cheese makers. The latter is applied to the milk, whey, or drainings from the curd at every stage of the process as long as the curd is in the vat. When following the development of acid in the cheese vat with any form of acidimeter, it is commonly the practice to add rennet to the milk when the acidity is about 0.18 per cent; to draw the whey and mat the curd when the whey acidity is about 0.17 per cent, so that, after stirring, the drippings titrate 0.24 to 0.30 per cent; to mill the curd when the drippings titrate 0.65 to 0.90 per cent; and to salt the curd when the acidity of the drippings has reached 0.90 to 1.2 per cent.[a]

No less important than acidity in its effect on the quality of the finished cheese is the moisture content. Throughout the process of making cheese, while in the vat, the effort is made to establish and maintain a proper relationship between the moisture and acid content of the curd.[b]

After the starter has been added and the vat heated little more can be done to either hasten or delay the bacterial development of acid. Therefore it is customary to watch the increase of acidity by using an acidimeter or rennet test, and to vary the operations which affect the moisture content to suit the observed rate of acid development. The following quotations express ideas which are prevalent to-day among cheese makers, and describe the methods used in Cheddar cheese factories in judging the moisture content of a curd. Decker[a] says:

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[a] Van Slyke, Lucius L., and Publow, Charles L. The science and practice of cheese making. New York, 1909. Pp. 31–37.

[b] Loc. cit., p. 45.

> When the whey is drawn, the curd must not be salvy and soft; but when a big double handful is pressed together in the hands and one hand removed it should not remain in a mashed-up mass, but should fall apart readily.

Efforts to develop a simple, rapid method of judging the moisture content more accurately than can be done by the feeling have been made at this station and at the Ontario Agricultural College.[b] Of late various rapid moisture tests for butter and cheese have been devised and placed on the market, but none as yet have come into general use in cheese factories. It is difficult to teach students to judge when curd is firm enough to be dipped by feeling it, and experienced makers do not always agree on this point.

The experience of practical cheese makers has shown that certain operations can be used with success for the purpose of more rapidly separating whey from curd when speed is necessary. On account of the crudeness of the method employed in judging these effects, namely, by the feeling of the curd when grasped, it is impossible to state at present which of the various contributing agencies is the most efficient in producing the desired result. It is difficult to understand these matters in the absence of more exact information respecting changes in the moisture content than can be obtained by squeezing the curd in the hand at various stages of the cheese-making process. On this point Van Slyke and Publow[c] say:

> The contraction or hardening of the pieces of curd is known as "firming." It is probably due primarily to escape of whey. What share temperature, rennet, and acidity each has in the process can not now be stated definitely.

Some determinations of moisture in curds in the vat at one stage or another are recorded in the literature on this subject, notably by Professor Dean in the Annual Reports of the Ontario Agricultural College and Experimental Farm, but a systematic and intimate study of the entire subject has not been reported.

PLAN OF PRESENT INVESTIGATIONS.

In view of what has been stated it was decided to make cheese under various well-defined conditions, to take samples of the curds at short intervals of time throughout the process of making, and to determine the moisture by drying and weighing. It was hoped to obtain more exact information respecting practical methods of controlling the moisture content of cheese by this means than has been heretofore available. The results are presented in a form which can be readily used by teachers and students of cheese making.

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[a] Decker, John W. Cheese making. Fifth revised edition, by F. W. Woll. Madison, Wis., 1909. Pp. 62-63.

[b] Dean, Henry H. A short test for determining the moisture in curd at dipping. Ontario Agricultural College and Experimental Farm, Thirty-second Annual Report, 1906, pp. 123-125. Toronto, 1907.

[c] Loc. cit., p. 27.

The work includes a study of the following important factors in cheese making: (1) Temperature; (2) size of cubes; (3) proportion of rennet; (4) acidity; (5) pressure; (6) proportions of fat and water in milk.

METHODS USED IN MAKING THE EXPERIMENTAL CHEESE.

The general plan was to make cheese in several small vats at the same time from equal weighed quantities of mixed milk. The milk in the large receiving vat was stirred steadily while portions were being drawn therefrom. The vats and apparatus were some of those used in giving instruction to large classes of students in cheese making.

In experimental work, where several vats of milk are to be handled simultaneously in accordance with prearranged plans, it is necessary to use smaller quantities of milk than would commonly be contained in a factory vat. The point where experimenters sometimes fail is in attempting to handle such large quantities of materials in an experiment that it is impossible to carry out with thoroughness the operations planned. It is believed that the quantity of milk used by us, usually 200 pounds in each vat, as well as the other conditions in the experiments described, were such that the work could be done with a high degree of accuracy, and that the results can properly be regarded as illustrating the principles involved in cheese-factory operations, whether conducted on a large or a small scale.

The four vats were handled daily by two operators, and, unless otherwise stated, were heated and set with rennet at 86° F. at intervals of five or ten minutes. The curds were cut in a uniform manner into one-half inch cubes, and heat was turned on fifteen minutes after cutting. The rate of raising the temperature was carefully equalized, and the steam was turned off thirty-five minutes after cutting. The whey was drawn two and one-half hours or more after cutting, and the curds were scooped onto racks. They were usually not stirred on the rack, and were kept at the desired temperature by warm water placed in the lower end of the vats. A curd mill was used, and 2½ pounds of salt was added for each 100 pounds of curd.

Rennet extract was measured accurately in a cylinder or graduated pipette. The thermometers employed were carefully compared with a standard instrument, and did not differ over one-half of a degree Fahrenheit.

The temperatures observed in cheese-making experiments are stated in terms of the Fahrenheit scale, since this is generally used in Cheddar cheese factories. Chemical analyses are described in terms of the Centigrade scale.

The time when each operation was performed and when each sample was taken was recorded as the work proceeded. Each day one part of the process was varied in the different vats, all other parts being performed alike.

METHODS OF DETERMINING MOISTURE.

To determine how the moisture content of the four curds differed, samples of each were taken at intervals of five, fifteen, thirty, or sixty minutes, as required, throughout the process. So long as the curds were in the whey the sampling of the curds was done by the use of a small dipper 3 inches in diameter and 1 inch deep, with a wire-strainer-cloth bottom. This was inserted to the bottom of the vat and lifted out after the entire vat contents had been set in motion by vigorously stirring with the hands. The samples thus obtained were freed from superficial moisture by placing them for a moment on sheets of filter paper, and then were quickly weighed in 10-gram portions into numbered tin boxes, which, with their covers and a small quantity of dried sand, weighed exactly 17 grams each. Curds out of the whey were sampled by inserting a long, sharp-edged brass sampling tube, and were not dried on paper. A balance sensitive to 0.005 gram was used in weighing samples. Duplicate moisture determinations were made on each sample of curd, and the results are given in the tables. The dishes of curd prepared each day were placed together on perforated metal trays in a double-walled cast-iron drying oven, heated with steam, which has been described elsewhere.[a]

Having in the oven 60 to 80 10-gram samples of curd, containing about 50 per cent of moisture, the weight of water to be evaporated was something like 300 grams. The oven door was opened at intervals during the first three hours to let the water vapor escape freely. The steam pressure being 45 to 50 pounds the temperature inside the oven stood at 110° to 120° C. during the first four hours, while most of the water was being evaporated, and later rose to 130°. It is best to weigh two or three dishes from the lot each day after four, six, and eight hours' heating, returning them to the oven between weighings, and to remove the entire lot of dishes from the oven after it has been demonstrated that loss of weight has practically ceased. When the oven contains only a few dishes the drying proceeds more rapidly. The perforated metal trays used to support the dishes permit free circulation of air within the oven. An arrangement for admitting previously heated air at the bottom, with an exit at the top, would probably shorten the time required for drying cheese samples to constant weight.

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[a] Farrington, E. H. A creamery method for the determination of water in butter. Wisconsin Agricultural Experiment Station, Bulletin 154, Madison, 1907.

Comparison was made between the high-pressure oven and a sheet-copper drying oven heated by live steam from the heating system reduced to atmospheric pressure by a reducing valve. The temperature stood at 90° C. Eight dishes, each containing 10 grams of a well-mixed curd sample, were placed in these 2 ovens, 4 in each. In the high-temperature oven there were also placed at the same time 56 other dishes of curd. The 8 dishes were removed from the ovens at intervals, the lids put on each time, and the dishes weighed when cool and immediately returned to the ovens. Table 1 shows that the loss in weight practically ceased in eight hours at 44.8 per cent loss in the high-temperature oven, and in one hundred and twenty hours at 44.4 per cent loss in the low-temperature oven. The latter would, no doubt, have come to constant weight sooner if the temperature had been nearer 100° C. From this it is concluded that the drying of curds for eight hours in the oven, heated by steam at 45 to 50 pounds pressure, gives practically correct results. Accordingly this oven was used in all of the following experiments, and the results are strictly comparable with each other.

TABLE 1.—*Loss of weight from curds when dried in the high and low temperature ovens.*

Total time heated.		Total loss in weight.		Loss in weight per hour.	
		High temperature.	Low temperature.	High temperature.	Low temperature.
Hrs.	*m.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
2	0	24.30	16.20	12.10	8.1
3	40	40.95	21.50	10.00	3.2
4	30	44.20	26.40	3.30	5.0
5	50	44.60	30.10	.30	3.0
8	50	44.80	35.40	.07	1.8
10	35	44.80	38.10	....	1.3
27	25	44.90	42.40	.005	.25
49	0	....	43.30	....	.04
65	0	....	44.00	....	.04
74	0	....	44.15	....	.016
98	0	....	44.30	....	.006
122	0	....	44.40	....	.004
266	0	....	44.50	....	.0007

MOISTURE CONTENT OF FOUR SIMILAR CURDS, SHOWING ACCURACY OF METHOD.

The degree of accuracy attainable under the prevailing conditions was determined, on several days, by handling the vats as nearly alike as possible and determining the moisture content of the four curds at regular intervals.

The following experiment is described because it shows the largest variations between duplicate vats which were observed at any time;

in the succeeding pages the agreement of results between different vats is closer in several cases. The milk had 4 per cent fat and 0.185 per cent acid when set. The curds were not stirred on the rack. The acidity of the whey when drawn was 0.205 per cent. The curds were dipped two and one-half hours, milled four hours, salted six hours, and hooped six hours and twenty minutes after cutting. The temperature in all vats when set was 86° F.; thirty-five minutes after cutting it was 104° F., and the same when the whey was drawn. The curds were milled at 100°, salted at 90°, and hooped at 85°. In Table 2, and in all the following tables, the moisture content of the curd when cut is given as 87 per cent, this figure being assumed and not determined by anlaysis.

TABLE 2.—*Moisture content of four curds made in different vats from mixed milk.*

Time after cutting.		Moisture in curd.											
		Vat I.			Vat II.			Vat III.			Vat IV.		
Hrs.	*m.*	*P. ct.*	*P. ct.*	*Average per cent.*	*P. ct.*	*P. ct.*	*Average per cent.*	*P. ct.*	*P. ct.*	*Average per cent.*	*P. ct.*	*P. ct.*	*Average per cent.*
0	0	......	......	87.0	......	......	87.0	......	......	87.0	......	......	87.0
0	30	78.2	78.4	78.3	77.7	77.8	77.8	80.0	78.7	79.8	79.0	79.0	79.0
1	0	67.7	67.6	67.6	67.5	67.5	67.5	66.5	65.8	66.2	67.1	66.5	67.3
1	30	61.4	61.5	61.5	63.6	64.1	63.9	61.5	61.8	61.7	61.1	60.5	60.8
2	30	55.9	55.9	55.9	56.8	55.8	56.3	54.2	56.0	55.1	54.9	54.4	54.7
3	0	45.6	45.6	45.6	44.9	45.3	45.1	46.2	45.4	45.8	44.0	43.8	43.9
4	0	41.0	41.2	41.1	42.1	42.7	42.4	41.1	40.7	40.9	41.3	42.0	41.7
6	0	38.9	39.1	39.0	38.6	39.6	39.1	38.8	39.2	39.0	38.9	39.0	39.0
6	20	35.8	36.0	35.9	37.0	37.1	37.0	36.3	36.3	36.3	36.5	37.1	36.8

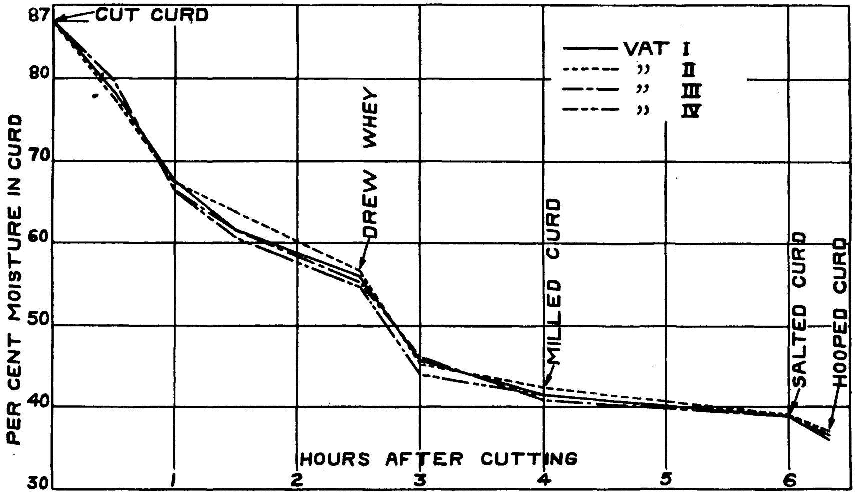

FIG. 1.—Curves showing experimental errors in determining the moisture content of four duplicate curds.

If we regard the average of two determinations as representing correctly the moisture content of the curd, it is seen in the experiment just described that the departure of any curd from the average moisture content of the four curds at the same time is, on the average, 0.53 per cent of the weight of the curd. In the same experiment the departure of any single moisture determination from the average of the pair is, on the average, 0.20 per cent of the weight of the sample.

The duplicate moisture determinations agree better with each other than do the four curds among themselves. The accurate sampling of curd in a vat is probably much more difficult than the determination of moisture in the samples. (See fig. 1.)

ACCURACY OF SAMPLING OF CURD IN THE VAT.

In all the experiments described one sample was taken from a vat at a time, and from each sample two portions of 10 grams each were weighed into tin dishes. To see how close an agreement could be had between the moisture content of samples taken from the vat in rapid succession, samples were drawn every five minutes during a two-hour period, previous to drawing the whey. The analytical data are given in Table 3. From this it can be seen that the methods used gave fairly satisfactory and uniform samples. The variations between successive samples are small. The departure of a moisture determination from the average of the pair was in this experiment 0.47 per cent of the weight of the curd, on the average, among the entire 30 samples. The average among the first 15 samples was 0.61 per cent, and among the last 15 samples 0.33 per cent, showing that the curds can be sampled with less difficulty and error during the later stages of the cheese-making process. The unavoidable variations observed in these preliminary experiments were smaller than the variations of moisture content which resulted from intentional modification of the cheese-making process, as shown in subsequent experiments. The acidity of the milk was 0.16 per cent when set, and the whey showed 0.125 per cent acidity when drawn, two and one-half hours after cutting. (See fig. 2.)

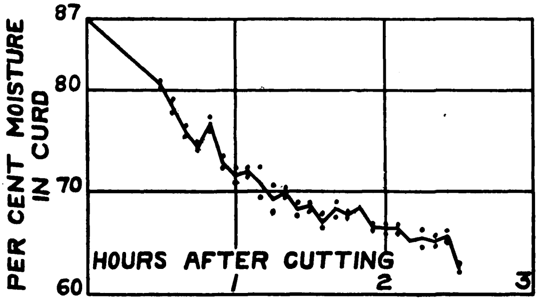

FIG. 2.—Duplicate moisture determinations to show accuracy of sampling. The two determinations (shown by lines of dots) and the averages (shown by solid line) indicate the degree of accuracy attained.

TABLE 3.—*Moisture in samples taken at five-minute intervals to determine accuracy of the method of sampling.*

Time after cutting.	Moisture found.			Time after cutting.	Moisture found.		
Hrs. m.	*Per cent.*	*Per cent.*	*Average per cent.*	*Hrs. m.*	*Per cent.*	*Per cent.*	*Average per cent.*
0 30	80.6	80.2	80.4	1 45	67.6	67.9	67.8
0 35	77.9	79.1	78.5	1 50	68.2	68.5	68.4
0 40	75.5	76.3	75.9	1 55	66.7	66.3	66.5
0 45	74.1	74.3	74.2	2 00	65.7	66.6	66.2
0 50	76.3	77.5	76.9	2 05	66.0	66.6	66.3
0 55	72.5	73.3	72.9	2 10	65.1	65.1	65.1
1 0	70.9	72.2	71.5	2 15	64.4	66.3	65.3
1 5	71.6	72.3	71.9	2 20	64.7	65.6	65.1
1 10	69.3	72.4	70.8	2 25	65.1	66.3	65.6
1 15	67.7	70.5	69.1	2 30	62.1	62.8	62.4
1 20	69.7	70.2	69.9	3 0	50.8	50.8	50.8
1 25	67.4	68.7	68.1	3 30	45.8	46.6	46.2
1 30	68.1	68.7	68.4	4 0	43.7	43.9	43.8
1 35	66.3	67.7	67.0	4 30	40.1	41.6	40.8
1 40	67.4	69.0	68.2	5 0	40.3	40.5	40.4

THE INFLUENCE OF TEMPERATURE ON THE SEPARATION OF WHEY FROM CURD.

The next effort was to determine how great is the effect of heat upon the process of removing moisture from curd by using different temperatures in the four vats and observing the moisture content of each curd at intervals. In a similar way various elements of the process other than temperature were studied. Each part of the work was repeated several times. The data, which are recorded herein, are representative in every case of several concordant experiments and are believed to be indicative of the effects which would be produced in any vat, large or small, under the conditions described.

THE USE OF FIXED TEMPERATURES FOR SETTING AND FIRMING.

In the experiment described below the milk contained 4 per cent fat, and was set with 4 ounces of rennet per 1,000 pounds at 86°, 92°, 98°, and 104°, respectively, in the four different vats. These temperatures were maintained until the whey was drawn, after which the curds were slowly warmed or cooled, as required, to bring them all to 86° when hooped. The milk began to thicken in twelve, ten, nine, and nine minutes, respectively, and the curds were cut into one-half-inch cubes in thirty, thirty, twenty-three, and twenty-three minutes after adding rennet. Care was exercised to have the cubes of uniform size, to maintain the different vats at the prescribed temperatures, and to handle them alike in all other respects. The curds were not stirred on the rack. The acidity of the milk in each vat was 0.17 per cent when set, and of the whey 0.155 per cent when drawn. The moisture content is given in Table 4. (See also fig. 3.)

TABLE 4.—*Moisture content of curds held at fixed temperatures from setting to dipping.*

Time after cutting.	Operation.	Moisture in curd.			
		Vat I. Temperature 86°.	Vat II. Temperature 92°.	Vat III. Temperature 98°.	Vat IV. Temperature 104°.
Hrs. m.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0 0	Cut.......	87.0	87.0	87.0	87.0
0 30	....	83.1	81.6	78.6	77.3
1 30	....	77.8	75.3	71.9	69.4
2 30	Dipped...	73.0	69.8	65.4	64.0
2 45	....	64.3	62.7	57.5	55.4
3 0	....	60.5	56.0	52.3	52.0
4 0	Milled....	53.9	49.7	47.0	45.5
6 0	Salted....	43.4	43.3	41.4	41.6
6 20	Hooped...	39.8	40.1	39.2	39.0

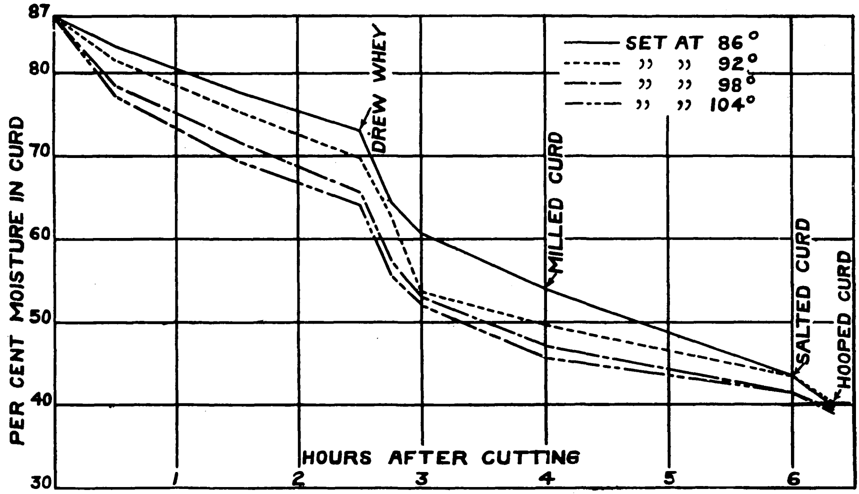

FIG. 3.—Effect of different temperatures at setting. Four vats were held at 86, 92, 98, and 104° from setting until the whey was drawn. It will be seen that the 98 and 104° curves lie close together.

The figures show that the temperature is a very important factor in the removal of moisture from cheese curds. Some 18 degrees difference in temperature made 9 per cent difference in moisture content when dipped. The fact that in this experiment the four curds, set and firmed at 86°, 92°, 98°, and 104°, respectively, had the same moisture content when hooped, shows that this is not wholly dependent on the moisture content when the whey is drawn, but is influenced by other important factors during the later stages of the process, which will be referred to again.

THE USE OF DIFFERENT TEMPERATURES FOR SETTING THE MILK.

In factory practice vats of milk are usually set at about 86° F. and later heated to a temperature in the neighborhood of 100°. When it is desirable, as with overripe milk, to shorten the time and to get the milk coagulated quickly, so as to cut and heat the curd as soon as possible, five or ten minutes may be saved by setting the vat as high as 96°, as suggested by J. W. Robertson,[a] though the loss of fat is slightly greater. However, since overripe milk thickens faster than sweet milk with rennet at 86°, many makers never use a higher temperature for setting than 86° at any time.

In the following experiment four vats of mixed milk of 0.20 per cent acidity were heated to 86°, 92°, 98°, and 104°, respectively, and set with 3 ounces of rennet. Each was cut in twenty-two minutes. Heat was turned on fifteen minutes after cutting, and the temperature was 104° in each vat thirty-five minutes after cutting. The acidity of the whey increased alike in the four vats, and this, with the moisture content of the curds, is shown in Table 5. (See also fig. 4.)

TABLE 5.—*Moisture content of curds from overripe milk set at 86°, 92°, 98°, and 104°, and heated to 104°.*

Time after cutting.	Acidity of whey.	Moisture content of curd.			
		Vat I, set at 86°.	Vat II, set at 92°.	Vat III, set at 98°.	Vat IV, set at 104°.
Hrs. *m.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0 0	0.135	....	....	....	....
0 35	....	77.7	76.3	74.9	73.0
1 0	.157	69.4	69.5	68.6	69.9
1 30	.18	65.6	63.5	62.4	65.5
2 0	.19	60.6	58.9	58.3	60.2
2 30	.25	56.1	56.1	55.7	59.0

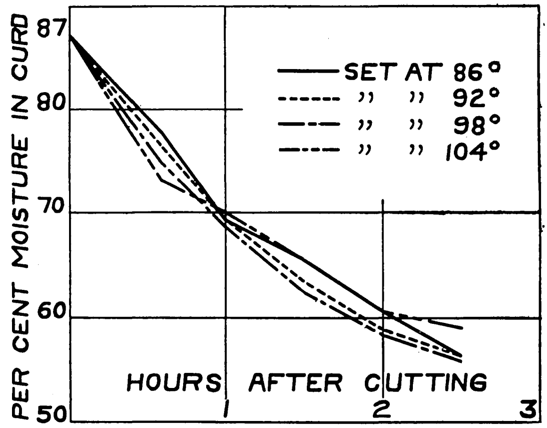

FIG. 4.—Effect of setting curds at different temperatures and heating to the same temperature after cutting. The curds differed widely in moisture content one-half hour after cutting, but were closely alike one hour after cutting.

The use of higher temperatures of setting induces more rapid separation of whey at first. When the curd is heated to 104° the moisture separates more rapidly at first but later at a decreased rate, so that within one hour after setting the moisture content is the same in curds I, II, and III. Curd IV, set at the highest temperature, shows the decrease in rate more markedly than the others and contains more moisture than curd III as early as one hour after cutting.

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[a] Monrad, J. H. A. B. C. in cheese making. Springfield, Ill., 1885. P. 29.

The practical application of these facts is as follows: With milk of this ripeness the whey would probably be drawn when the acidity was 0.18 per cent, one and one-half hours after cutting. Under these conditions a curd set at 98° will be the driest, and the others will contain more moisture in order, as set at 92°, 86°, and 104°. With milk of such high acidity handled in this manner the use of 104° does not get the curd any drier than 86°, nor as dry as 92° or 98°.

A possible explanation for these facts may be that a very rapid initial rate of removal of moisture (to less than 74 per cent in vat IV in one-half hour after cutting) may separate moisture from the surface layer of curd faster than the moisture can move from the center to the surface, thus forming a relatively dry and impervious layer of curd at the surface through which the remaining moisture passes more slowly.

Another experiment was performed in a similar manner with milk of lower acidity, and is described here for convenient comparison with the preceding.

Mixed milk of 0.16 per cent acidity and 4 per cent fat content was placed in four vats, which were heated to 86°, 92°, 98°, and 104°, respectively, and set with 4 ounces of rennet per 1,000 pounds of milk, but without the addition of any starter. The acidity of the whey rose slowly and reached 0.16 per cent two and one-half hours after the curds were cut, at which time the whey was drawn. Each curd was cut twenty-six minutes after adding rennet, heated fifteen minutes later, and reached 104° thirty-five minutes after cutting. The moisture content of the four curds is shown in Table 6 and figure 5.

TABLE 6.—*Moisture content of curds set at 86°, 92°, 98°, and 104° and firmed at 104°.*

Time after cutting.	Moisture in curd.			
	Vat I, set at 86°.	Vat II, set at 92°.	Vat III, set at 98°.	Vat IV, set at 104°.
Hrs. m.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0 0	87.0	87.0	87.0	87.0
0 30	81.6	80.3	77.7	75.7
1 0	72.2	71.9	71.7	71.0
1 30	67.6	68.0	69.3	68.4
2 30	62.7	62.9	62.0	62.8

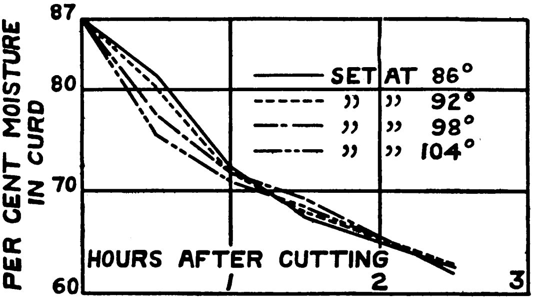

FIG. 5.—Effect of conditions same as in figure 4, but with milk not so ripe. Note the wide variation at first and the close agreement after one hour.

In this case, where the milk was sweeter, the initial rate of removal of moisture was less than in the experiment preceding. Curd IV contained more than 75 per cent of moisture one-half hour after cutting. Under these conditions the vats set highest lost moisture more quickly at first and more slowly after one-half hour, so that they all had practically the same moisture content one, one and one-half, and two and one-half hours after cutting. There is therefore no advantage in using a higher temperature than 86° in such a case. With milk that is not overripe 86° is commonly employed for setting the vat for several reasons—it is high enough to permit ripening of the milk, it insures a reasonably rapid rate of coagulation with rennet, the loss of fat is low, and the curd can be freed from moisture quite as thoroughly on raising the temperature after cutting as it could be if a higher temperature had been used for setting the vat.

HEATING THE CURD AFTER CUTTING.

While milk is quite generally set at 86° in Cheddar cheese factories, the practice varies as to the temperature used in "cooking" the curds after cutting. Many makers ordinarily use 98°, others 100° or 102°, a smaller number use 104°, and a few, though it is difficult to say how many, heat the curd as high as 106°, 110°, or 114° in the whey.

To determine the influence of different temperatures on the rate of moisture separation, four vats of milk, containing 4.2 per cent fat and 0.182 per cent acid were set at 86° with 3 ounces of rennet per 1,000 pounds. All were cut alike thirty-five minutes later, and fifteen minutes after cutting steam was turned on three of them. In thirty-five minutes after cutting the four vats were at 86°, 98°, 104° and 110°, at which temperatures they were held until the whey was drawn. The curds were then slowly warmed or cooled, as required, to bring them to about 86° at the time they were hooped. The whey acidity was 0.185 per cent when drawn. The curds were put on the rack and matted without stirring. The drainings from the rack after milling contained 18, 14, 14, and 34 grams of fat, respectively, the temperatures of the curds when milled being 88°, 94°, 100°, and 102°. The moisture content is shown in Table 7. (See also fig. 6.)

TABLE 7.—*Moisture in curds cooked at 86°, 98°, 104°, and 110°.*

Time after cutting.	Operation.	Moisture in curd.			
		Vat I, cooked at 86°.	Vat II, cooked at 98°.	Vat III, cooked at 104°.	Vat IV, cooked at 110°.
Hrs. m.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0 0	....	87.0	87.0	87.0	87.0
0 30	....	82.2	80.1	80.2	81.0
1 30	....	76.3	69.3	67.3	62.9
2 30	Drawn.............	73.6	63.7	62.0	57.9
3 0	....	58.0	50.0	46.2	43.6
4 0	Milled..............	52.0	44.0	41.9	41.6
6 20	Hooped............	40.4	37.3	35.6	34.3

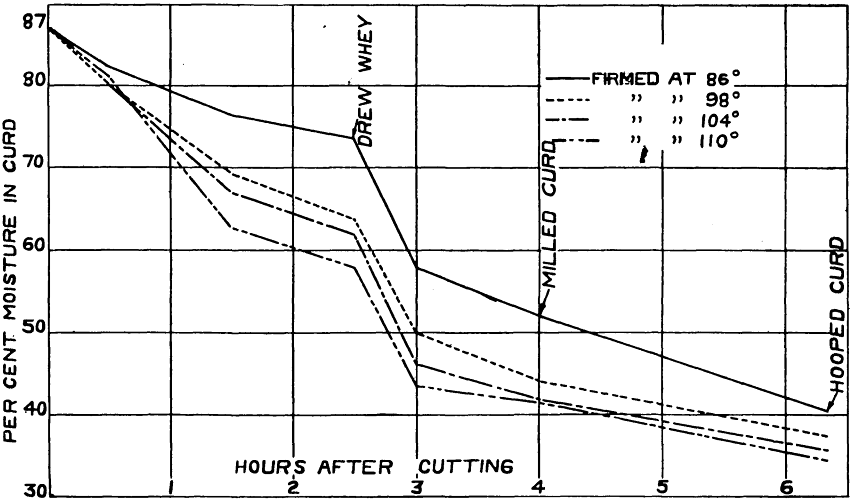

FIG. 6.—Effect of setting the milk at the same temperature and heating to different temperatures. Four vats were set at 86°, but firmed at 86, 98, 104, and 110°. Note the small differences between the 98 and 104° curves, as is also shown by figure 3.

The temperature to which the vat is heated after cutting has a very marked influence on the rate of removal of moisture while the curd is in the whey. The higher the temperature the more rapid the separation of whey under the conditions described.

TIME AND RATE OF HEATING THE VAT AFTER CUTTING.

With respect to the time of beginning to heat the vat after cutting, and the rate at which it should be heated, Monrad[a] quotes the following directions from Robertson's "Pointers for Cheese Factories:"

> The application of heat should be delayed for fifteen minutes after stirring is commenced. The temperature should be gradually raised to 98° F. at a rate not faster than 1° every four or five minutes. In the case of a quick curd these rules may be disregarded.

On the same subject Decker[b] says:

> Curd being a poor conductor of heat, a rise of 1° in five minutes is fast enough to heat normal working milk. If it is heated too fast it will cook the particles on the outside and retain the whey inside of the curd.

Van Slyke and Publow[c] give the following directions:

> Care must always be taken not to raise the temperature of the curd too rapidly. Usually the temperature can be raised 2° in every five minutes, but when the lactic acid formation is slow 1° every five minutes may be sufficient. If after cutting the whey around the curd shows 0.12 per cent acidity, allow sixty minutes for heating; if 0.15 per cent acidity, allow twenty minutes for heating. Applying heat too fast hardens the outside of the curd and prevents the escape of the whey.

The practice of beginning to heat the vat very soon after cutting the curd, and raising the temperature rapidly, is followed almost solely when the milk is overripe. Some cheese makers intentionally ripen milk to 0.20 per cent acidity or more and habitually apply heat in this manner. Experiments were undertaken to determine whether by such treatment the moisture content is reduced more rapidly than by the usual slower method of heating.

In one experiment milk of 0.20 per cent acidity in four vats was set with 4 ounces of rennet and cut with ½-inch knives in twenty-five minutes. The first and second vats were heated to 104° and the third and fourth vats to 110°. The first and third vats were stirred fifteen minutes and were heated in twenty minutes; the second and fourth were stirred six minutes before heating and were heated in seven minutes. The acidity of the whey when drawn was 0.215 per cent. The time of each operation and the moisture content of the resulting curds are shown in Table 8. The curds were not stirred on the rack. The comparative effect of rapid and slow heating is illustrated in figure 7.

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[a] Loc. cit., p. 30.
[b] Loc. cit., p. 60.
[c] Loc. cit., pp. 30–31.

TABLE 8.—*Moisture in curds heated slowly and rapidly to 104° and 110°.*

Time after cutting.	Operation.	Moisture in curd.			
		Vat I (heating begun at 15 minutes and reached 104° at 35 minutes).	Vat II (heating begun at 6 minutes and reached 104° at 11 minutes).	Vat III (heating begun at 15 minutes and reached 110° at 35 minutes).	Vat IV (heating begun at 6 minutes and reached 110° at 11 minutes).
Hrs. m.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0 0	....	87.0	87.0	87.0	87.0
0 30	....	76.2	73.9	77.6	73.2
1 0	....	65.5	67.3	64.7	65.2
1 30	....	61.5	64.7	60.2	61.5
2 30	Drawn....	53.2	59.0	55.5	58.4
3 0	....	45.0	47.2	45.6	46.3
4 0	Milled.....	41.7	42.5	40.4	41.9
6 0	Salted.....	39.9	39.6	37.2	37.2
6 20	Hooped...	37.8	37.0	33.9	33.2
Whey fat (per cent)..		0.175	0.20	0.22	0.25
Yield of green cheese per 100 pounds milk (pounds)...........		9.5	9.32	9.07	8.8

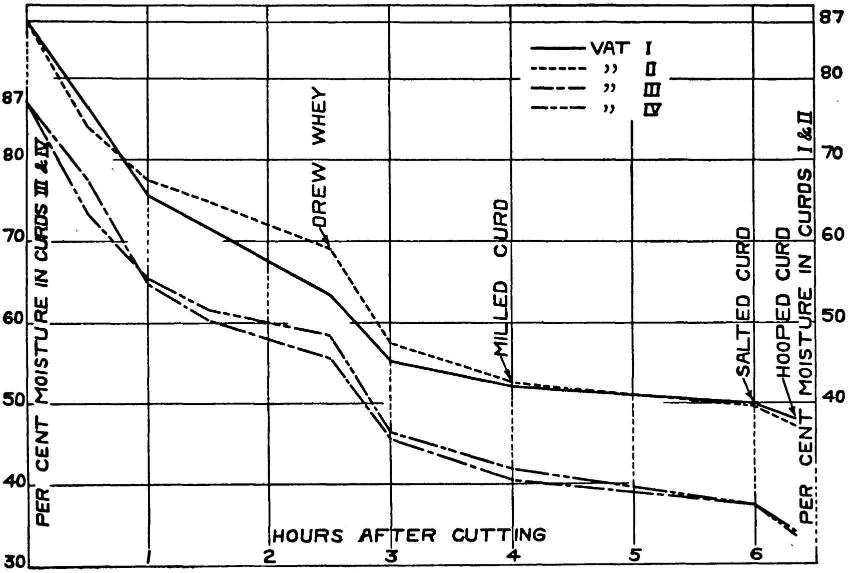

FIG. 7.—Effect of rapid and slow heating. Two vats (I and III) were heated slowly to 104 and 110°, respectively. Two other vats (II and IV) were heated rapidly to the same temperatures. Note that the curves cross at about one hour after cutting. The two pairs of curves are separated so as to be more readily traced.

The results obtained at 110° and 104° show that at both temperatures early and rapid heating caused more rapid separation of whey during part of the first hour, but after the first hour the separation of moisture was slower than when the ordinary method of heating was used. The rapidly heated curds contained as much or more moisture two and one-half hours after cutting than did the more slowly heated curds. In other similar experiments the same general results were obtained.

There is a greater loss of fat in the whey and a smaller yield of cheese from each of the more rapidly heated vats, instead of a larger yield. These facts are of importance to those cheese makers who habitually ripen milk to a high percentage of acidity and heat the curd as rapidly as possible after cutting, with the object of obtaining a larger yield, due to water being retained within the toughened walls of the cubes. The fact is that these walls break under the pressure as soon as the curd is piled up to mat, and the liquid contents escape, partly at this stage and partly after milling, in the form of white whey of high fat content. As a result the yield of cheese is less, instead of more, than that obtained when the skin-and-pulp condition of curd is avoided.

It was observed that in vats II and IV, which were heated rapidly, the surface of the cubes became tough, while the interior remained soft and pulpy, the cubes thus losing homogeneity, which did not occur in vats I and III. The moisture content of the two 110° curds was about 4 per cent lower than that of the two 104° curds when hooped.

Another experiment was carried out in which sweeter milk was used than in the last, as follows: Four vats of fresh mixed milk of 4 per cent fat content and 0.162 per cent acidity were set at 86°, with 4 ounces of rennet per 1,000 pounds. Each was cut thirty minutes later. The time and rate of heating were varied and are indicated in Table 9, together with the moisture content of the curds. The acidity of the whey was 0.112 per cent when the curd was cut and 0.132 per cent two and one-half hours later when the curd was dipped. The results show that the different methods of heating had a marked effect on the moisture content early in the process, but owing to lack of acidity the curds all practically stopped firming when the moisture content reached about 65 per cent. The differences in moisture content, so marked at first, were thus lost. The difference in behavior between curds from ripe milk and from sweet milk will be referred to again in the discussion of acidity. The results of this experiment are shown in figure 8.

TABLE 9.—*Influence of rapid and early heating on the moisture content of curds from sweet milk.*

Time after cutting.	Vat I (began to heat at 15 minutes and reached 104° at 35 minutes).	Vat II (began to heat at 15 minutes and reached 104° at 25 minutes).	Vat III (began to heat at 30 minutes and reached 104° at 35 minutes).	Vat IV (began to heat at 5 minutes and reached 104° at 10 minutes).
Hrs. m.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0 0	87.0	87.0	87.0	87.0
0 30	80.5	78.1	83.0	74.3
1 0	73.8	71.9	72.5	68.0
1 30	68.8	68.0	68.4	66.9
2 0	66.7	66.2	65.7	....
2 30	65.2	64.4	64.6	64.6

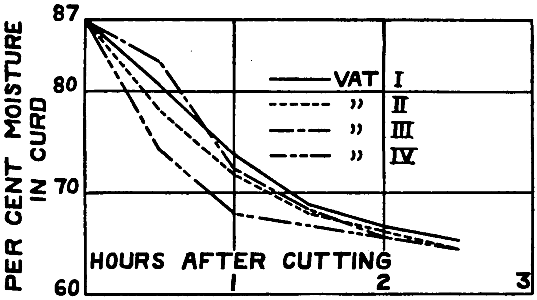

FIG. 8.—Effect of heating curd rapidly after cutting. The curds which were heated most quickly to 104° after cutting lost moisture most rapidly at first, but in two hours after cutting these differences had disappeared.

INFLUENCE OF SIZE OF CUBES ON MOISTURE IN CURD.

It is generally believed that the smaller the cubes into which a curd is cut the more rapid will be the separation of whey; also that when a curd is cut into pieces of irregular size the smallest ones become firm first. To show definitely what differences of moisture content are produced by using different sized knives the following experiment will be described.

Four vats of milk, acidity 0.20 per cent, were set with 3 ounces of rennet at 86° and each was cut twenty-five minutes later. The curds were cut with different-sized knives, but in all other respects were handled exactly alike. They were not stirred on the racks, and were hooped at 86°. The whey acidity was 0.225 per cent two and one-half hours after cutting the curd. (See Table 10 and fig. 9.)

TABLE 10.—*Moisture content of curds cut with different-sized knives.*

Time after cutting.	Operation.	Moisture in curd.			
		Vat I, cut with ¼-inch knives.	Vat II, cut with ⅜-inch knives.	Vat III, cut with ½-inch knives.	Vat IV, cut with ¾-inch knives.
Hrs. m.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0 0	....	87.0	87.0	87.0	87.0
0 30	....	75.5	77.0	79.7	85.6
1 30	....	56.5	61.3	65.6	76.5
2 30	Dipped...	49.7	52.9	58.2	69.8
3 0	Milled.....	39.5	43.1	46.3	49.8
6 0	Salted.....	38.2	41.0	42.7	46.6
6 20	Hooped...	33.9	35.6	35.6	38.3

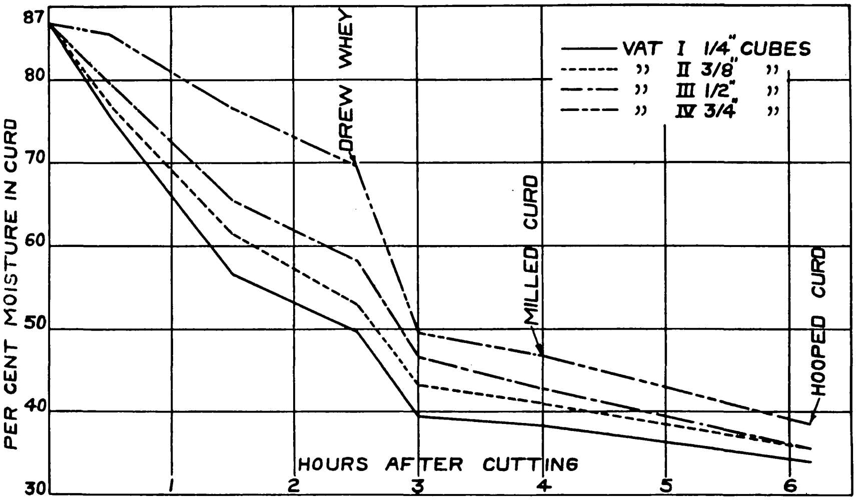

FIG. 9.—Effect of cutting the curd with different-sized curd knives. Note especially the curves for vats II and III.

The difference in moisture content between the curds was much greater just before drawing the whey than when the curds were hooped. The moisture content of the ⅜-inch cubes reached 58 per cent about forty-five minutes earlier than the ½-inch cubes. A pair of ⅜-inch knives might well be included in every factory outfit. The advantages of using the ⅜-inch knives instead of cutting the curd many times with the usual ½-inch knives are quicker cutting, more uniform size of cubes in the vat, and more uniform size of cubes on successive days. The ⅜-inch and ¼-inch curd knives used in this experiment were made with staggered blades, as shown in figure 10, so that the compression which the curd undergoes in passing between the blades is decreased. There is no difficulty in cutting the curd into cubes of uniform size with knives constructed in this manner.

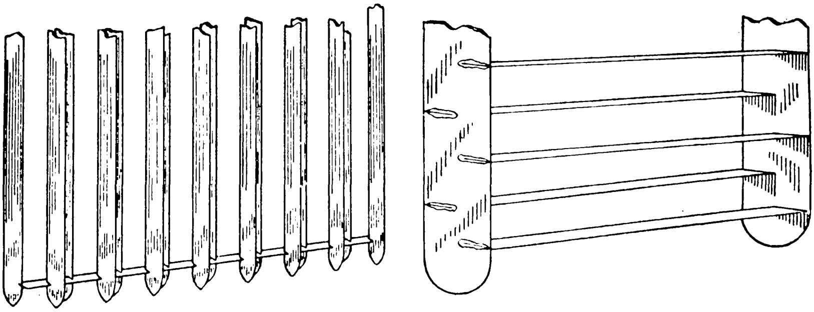

FIG. 10.—Two curd knives with staggered blades which were used to allow the curd to pass through with less compression than if the blades were all in the same plane.

The difference in rate of moisture separation, where the different-sized knives were used, is no doubt related to the fact that the surface area of all the cubes cut from a curd is inversely proportional to the distance between the blades of the knife used. The smaller the cube, the less is the distance which moisture travels in passing from center to surface of the cube.

Table 11.—*Number and dimensions of cubes cut with different-sized knives.*

Distance between blades of knives.	Number of cubes per cubic foot.	Solid contents of cube.	Area of surface of cube.	Surface area of all cubes per cubic foot.
Inch.		*Cu. in.*	*Sq. in.*	*Sq. in.*
Three-fourths	4,096	0.422	3.375	13,824
One-half	13,824	.125	1.50	20,736
Three-eighths	32,768	.053	.844	27,656
One-fourth	110,592	.0156	.375	41,472

EFFECT OF RENNET UPON SEPARATION OF MOISTURE FROM CURD.

It is sometimes supposed that variations in the proportion of rennet, within reasonable limits, influence the rate at which moisture is expelled from curd. Quoting from J. W. Robertson's "Pointers for Cheese Factories," Monrad[a] says:

> The more rennet there is used the more moisture will be retained in the cheese under similar conditions. When milk is overripe or acidy a proportionately increased quantity of rennet should be used to effect a sufficient separation of the moisture from the curd (often termed "cooking") before the presence of lactic acid is perceptible to the taste or smell or is discernible by the hot-iron test.

Scherer[b] says:

> The stronger the action of the rennet and the sooner the casein is thrown down the more powerful the contraction of the curd and the larger the volume of whey expressed. This means a reduction in the residual water in the curd and an increase in its final dryness and firmness.

H. H. Dean[c] says:

> It is thought by some that a large quantity of rennet produces a cheese with a great deal of moisture. This is not so, but rather the reverse. The length of time from setting to dipping and from dipping to salting the curd does not seem to be affected by the quantity of rennet used in the milk.

F. J. Lloyd,[d] who studied factory conditions in England, writes:

> If an excess of rennet be employed, then when the scald is applied the curd is drawn together too rapidly and the whey is expressed before it has had time to per-

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[a] Loc. cit., p. 29.

[b] Scherer, Robert. Casein: Its preparation and technical utilization. Translated from the German by Charles Salter. New York, 1906. P. 7.

[c] Dean, Henry H., Canadian dairying. Toronto, 1903. P. 162.

[d] Lloyd, F. J. Report on investigations in Cheddar cheese making, 1891–98. London, 1899. P. 104.

form its proper function, namely, to enable the bacteria feeding on it to bring about the desired acidity within the curd. An excess of rennet, by contracting the curd with too much force, may also cause some of the fat to be pressed out of it and lost in the whey.

As these quotations indicate, the ideas prevalent at present on this subject are based largely on conjecture.

It is well known that when more rennet is used the milk thickens quicker and the curd is ready to cut sooner and is less fragile after cutting, but whether the curd after cutting gives up whey any faster is a question yet to be answered.

In the following experiment four vats were set with 2, 3, 4, and 6 ounces of rennet per 1,000 pounds, respectively, and were cut forty minutes later. The moisture content of the curds at different stages are indicated in Table 12 and figure 11.

TABLE 12.—*Influence of quantity of rennet on the separation of whey.*

Time after cutting.		Operation.	Moisture in curd.			
			Vat I, rennet 6 ounces.	Vat II, rennet 4 ounces.	Vat III, rennet 3 ounces.	Vat IV, rennet 2 ounces.
Hrs.	*m.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0	0		87.0	87.0	87.0	87.0
0	30		81.0	81.0	79.1	78.2
1	10		66.8	66.8	67.7	65.6
1	50		63.0	61.0	62.9	60.7
2	30	Dipped	58.2	55.2	56.5	56.3
3	0		45.4	46.0	46.2	45.8
4	0	Milled	42.0	42.3	42.0	42.5
5	0	Salted	41.0	40.7	40.9	41.0
5	30	Hooped	37.8	37.5	37.8	37.8

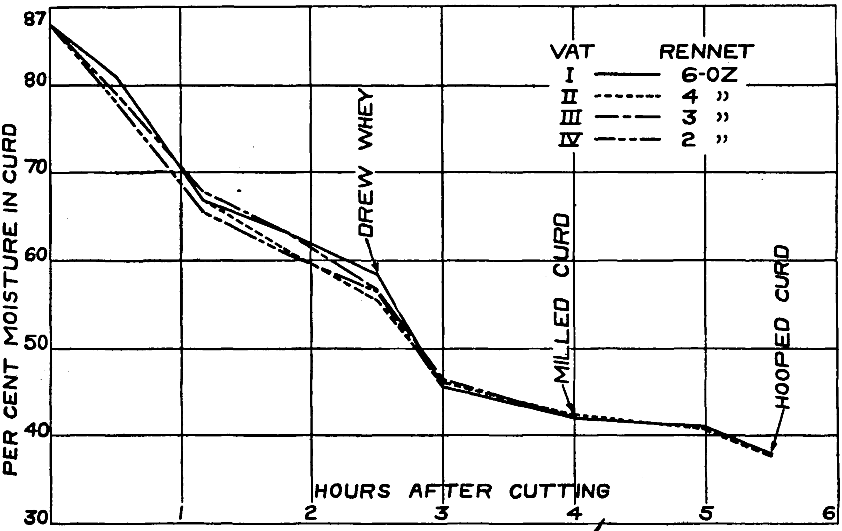

FIG. 11.—Effect of the use of different amounts of rennet. The differences in these curves are no greater than those in figure 1, due to experimental error. It will be seen that the use of different amounts of rennet did not affect the rate of separation of whey after cutting.

The moisture content of these four curds did not differ widely at any time. The variations are no greater than the unavoidable variations due to errors in cutting, sampling, etc., shown in Table 2 and figure 1. The curd with least rennet appears to have lost moisture a very little faster at first than the others, which slight difference, if it did occur, may have been due to slightly greater fragility of the low-rennet curd.

The conclusion from these and other similar experiments is that the rate at which curds lose moisture after cutting is not affected by variations in the proportions of rennet extract between 2 and 6 ounces per 1,000 pounds of milk.

The cheese maker saves time by using more rennet, for the reason that the curd gets thick enough to cut more quickly, and can be stirred and heated a little sooner after cutting. When a small proportion of rennet is used a more fragile curd may be obtained, and this may be more extensively broken into smaller pieces during the stirring process, and the separation of moisture thereby hastened. But this effect, if it occurs, is directly due to the size of the pieces of curd and only indirectly to the proportion of rennet.

LENGTH OF TIME FROM SETTING TO CUTTING.

Monrad[a] quotes Robertson as follows:

> The results of late investigations recommend that the curd be allowed to become fairly firm before it is cut, except in the case of a quick-working curd. More moisture is retained in the cheese and a better yield is thus obtained.

Van Slyke and Publow,[b] writing on the control of moisture in cheese making, say:

> When the curd is cut before it becomes hard, the whey escapes more easily than in the case of curd cut after it becomes hard. * * * Among the most common causes of excessive water in curd and cheese are the following: (1) Cutting curd coarse or when too hard. * * *

Since increase in the proportion of rennet does not affect the rate at which moisture separates from a curd, it might be expected that the length of time the rennet is allowed to act before the cutting of the curd would not influence the rate of moisture separation. That this is true was shown by several experiments, one of which is described below.

Two vats of milk of 0.165 per cent acidity were heated to 86° at the same time and rennet extract added at once to one at the rate of 4 ounces per 1,000 pounds. Both vats were held at 86° and rennet was added to the second vat sixty minutes later. The milk had visibly thickened twelve minutes later. As the vats were kept warm for the same length of time, the acidity of the milk or whey was alike in the two. In vats I and II, respectively, the curds were cut one hour and twenty-six minutes, and thirty-two minutes after adding rennet. The acidity of whey in each was 0.125 per cent when cut and 0.18 per cent two and one-half hours later, when drawn. The moisture content of the curd is shown in Table 13. (See also fig. 12.)

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[a] Loc. cit., p. 49.

[b] Loc. cit., pp. 46–49.

TABLE 13.—*Moisture of curds cut, respectively, eighty-six minutes and thirty-two minutes after adding rennet.*

Time after cutting.	Operation.	Moisture in curd.	
		Vat I, cut 86 minutes after adding rennet.	Vat II, cut 32 minutes after adding rennet.
Hrs. m.		*Per cent.*	*Per cent.*
0 0	....	87.0	87.0
0 30	....	79.25	78.8
1 30	....	66.9	66.8
2 30	Dipped...	59.2	60.8
3 0	....	45.2	44.8
4 0	Milled.....	42.5	42.7
5 0	Salted.....	39.9	40.4
5 20	Hooped...	38.3	38.3

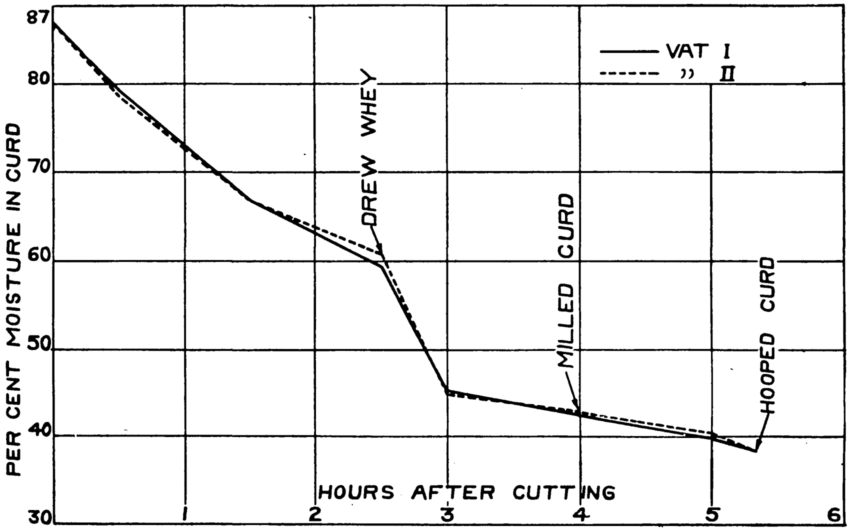

FIG. 12.—Effect of different periods of action by the rennet. It will be seen that the length of time the rennet acted on the curd from setting to cutting does not affect the rate at which the moisture separates after cutting.

From these experiments it is concluded that the rate of separation of moisture is not directly affected by the action of rennet for periods differing by one hour previous to cutting. If the curd develops more acid as a result of standing longer before cutting, any observed difference in the rate of whey separation may be due to the increased acidity but not to more prolonged action of rennet before cutting. If a curd is cut so early that it is very fragile and breaks up badly, any increased rate of firming must be ascribed directly to the decreased size of the particles of curd and not to the period of time from setting to cutting.

In another experiment 1,000 pounds of milk was pasteurized at 160° to 165° in a continuous pasteurizer of the disk type. The milk was then collected in one large vat, thoroughly mixed, and four 200-pound portions were placed in the experimental vats. The acidity was 0.16 per cent after pasteurizing, and in order to make the milk coagulate easily with rennet the acidity was raised to 0.20 per cent by adding 453 c. c. of dilute hydrochloric acid to each vat. One vat was set with rennet at the rate of 2 ounces and the other three vats at the rate of one-fourth ounce. The three latter vats were cut three, four, and five hours, respectively, after adding rennet. The milk was pasteurized to prevent ripening during these periods. The curds were handled in a uniform manner in all respects, unless otherwise stated. The time of the various operations and the moisture content of each curd is shown in Table 14.

TABLE 14.—*Effect of varying the proportion of rennet and the time from setting to cutting upon the rate of moisture separation.*

Time after cutting.		Moisture in curd.			
		Vat I, $\frac{1}{4}$ ounce rennet; curd cut in 5 hours.	Vat II, $\frac{1}{4}$ ounce rennet; curd cut in 4 hours.	Vat III, $\frac{1}{4}$ ounce rennet; curd cut in 3 hours.	Vat IV, 2 ounces rennet; curd cut in 40 minutes.
Hrs.	*m.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0	0	87.0	87.0	87.0	87.0
0	30	80.8	80.4	80.7	81.4
1	0	74.3	74.4	73.1	73.0
1	30	71.1	70.7	70.7	71.4
2	0	68.1	68.5	67.9	67.3
2	30	67.4	67.0	67.0	66.2

The figures are practically identical for the four vats, showing that where acidity does not rise by ripening, the rate of moisture separation is not affected by variations in the time from setting to cutting, nor in the proportion of rennet used.

INFLUENCE OF ACIDITY ON MOISTURE OF CURD IN VAT.

In discussing this topic it is necessary to consider the sources of acidity and the accuracy with which the acid content of a curd can be determined by the methods in common use.

FORMATION OF ACID WITHIN THE CURD.

Acidity is commonly developed in milk for cheese making by bacterial ripening. Since most of the bacteria present in milk remain in the curd [a] during the separation of whey, it follows that the principal seat of acid formation in the cheese vat is in the curd. This fact may be demonstrated by two simple experiments, as follows:

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[a] L. D. Bushnell, bacteriologist, formerly in the employ of the Dairy Division, found that 95 to 98 per cent of the bacteria present in milk are retained in the curd after the latter has been cut into cubes.

1. Soon after cutting the curd take a pint of the whey from the vat and place it in a small tin bucket. Hang this in the vat so as to keep it at the same temperature as the vat. Determine the acidity of the whey in the bucket and that in the vat at thirty-minute intervals. After the portion of whey is removed from contact with the curd its acidity remains practically constant for several hours, while the acidity of the whey in the vat increases steadily, showing that increased acidity of whey is a result of contact with curd and transfer of acid therefrom.
2. Place a portion of curd with some whey in a bucket soon after cutting and keep it warm, as before. Pour the whey out of the bucket as fast as it separates from the curd, leaving only enough whey to keep the curd covered, and stir to prevent matting. Determine acidity of whey in bucket and vat at intervals. In the bucket, where the proportion of whey to curd is smaller than in the vat, the acidity of the whey rises more rapidly than in the vat. This is because the acid coming out of the curd in the bucket is diluted with a smaller proportion of whey than is the case in the vat, and it shows that the rate at which the acidity of whey rises depends on the proportion of curd in contact with it, and that therefore the curd is the principal source of acid.

DETERMINATION OF ACIDITY WITHIN THE CURD.

As ripening progresses, the concentration of acid within the curd rises higher than in the surrounding whey on account of the bacterial activity in the curd. This is shown by the following experiment:

To 1,000 pounds of milk of 0.16 per cent acidity was added 1 pound of starter, and after ripening for one hour at 86° the vat was set with 4 ounces of rennet per 1,000 pounds, and cut thirty minutes later. Heat was applied fifteen minutes after cutting, and the temperature reached 100° fifteen minutes later. The whey above the curd was titrated at frequent intervals, the vat being stirred well before sampling. The ratio of acid to moisture within the curd—that is, the concentration of the acid solution within the curd—was also determined by taking representative samples of the curd, removing adhering moisture by the use of filter paper, and making determinations of moisture and of acid therein.

Two 10-gram portions of each sample were used for moisture determination in the usual manner. Two 10-gram portions were at once placed in two clean porcelain mortars, rubbed with clean quartz sand and water, filtered on absorbent cotton, and washed by decantation in the mortar (the sand may be omitted). In previous work it has been found that the curd, ground in cold water, made a very sticky emulsion, which could not be filtered on paper or cotton, but by the addition of warm water to the mass of curd and sand the fine particles of curd collected quickly in a loose, friable cake, so that the aqueous solution of lactic acid could be decanted and filtered with no trouble or delay. The cake of curd and sand was then ground with more water and decanted. Very hot water makes the ground curd form a rubbery mass, which can not be ground up, but water at 60 to 70° C. permits the curd to be washed rapidly and completely.

The filtrate from each 10-gram portion of curd, amounting to 200 c. c., was turbid from fat globules, but contained no suspended curd particles, and was titrated with N/10 caustic alkali, using phenolphthalein.

Knowing the weight of moisture (*a*) in 10 grams of curd and the weight of acid (*b*) extracted from 10 grams of the same, the percentage of lactic acid in the water contained in the curd is calculated by dividing *b* by *a*. The results thus obtained are given in Table 15. The acidity of the whey within the curd reached 0.62 per cent when the acidity of whey surrounding the curd was 0.215 per cent. Under these conditions it is clear that the determination of the acidity of whey, by titration, does not indicate exactly the concentration of acid in the solution within the curd. (See fig. 13.)

TABLE 15.—*Acidity of whey outside and inside of the curd.*

Time after cutting.		Acidity of whey outside of curd.	Acidity of whey inside of curd.
Hrs.	*m.*	*Per cent.*	*Per cent.*
0	30	0.115	0.154
0	50	.125	.178
1	10	.127	.215
1	30	.140	.257
2	0	.147	.295
2	20	....	.359
2	50	.176	.442
3	20	.190	.48
3	50	.215	.62
4	10	.225	....

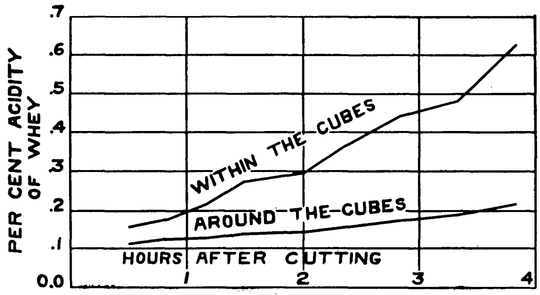

FIG. 13.—Showing the proportions of acid within and around the cubes in the vat. The acidity of the whey within the cubes rose to 0.62 per cent, while that of the surrounding whey reached only 0.22 per cent.

EXPERIMENTS AT CONSTANT AND VARYING ACIDITY.

If milk at any degree of acidity—as 0.25 per cent—is pasteurized before adding rennet, the acidity of the whey in or surrounding the curd does not increase during two or three hours after cutting. While pasteurization has not been widely used in practical cheese making, it is used in experimental work where it is desired to hold milk at a definite acidity for some hours during the cheese-making process. When the acidity of whey does not change during the process of firming it is clear that the concentration of acid within the curd is no greater than in the surrounding whey, and titration of the surrounding whey indicates also the acidity of the whey retained in the curd. By adding to pasteurized milk, either before or after pasteurizing, any desired proportion of hydrochloric or other acid, avoiding coagulation by acid, the acidity of the milk and of the whey, after cutting the rennet curd, may be brought to any figure required for experimental purposes, and held there as long as bacterial action is suppressed. There is thus afforded opportunity for studying the removal of moisture from curd in the following ways:

1. Under conditions of constant acidity, or either high or low concentration, produced either by the action of bacteria or by the addition of acid to the milk.
2. Under conditions of changing acidity as observed in the cheese vat under factory conditions.

It is believed that the study of results obtained under fixed conditions of acidity will enable us to understand more readily the effect of changing conditions of acidity which occur in the factory cheese vat.

SEPARATION OF MOISTURE FROM CURD AT CONSTANT ACIDITY BY HYDROCHLORIC ACID.

An experiment was made with 1,100 pounds of milk of 0.17 per cent acidity, pasteurized at 150° in the Farrington duplex pasteurizer, and 200-pound portions placed in three vats. The acidity of one of these was raised to 0.25 per cent, calculated as lactic acid, by adding a pound of dilute hydrochloric acid; another vat was raised to 0.20 per cent with acid, and one was kept at 0.17 per cent. All were heated to 86° and set with rennet at the rate of 3 ounces per 1,000 pounds. The curds were cut into ½-inch cubes, and fifteen minutes after cutting heat was applied to each; twenty minutes later all had reached 104°. There was practically no increase in acidity in three hours or more after cutting.

The moisture content and acidity of whey in these vats is shown in Tables 16 and 17, and the effect of acidity on rate of separation of whey from curd is shown in figure 14.

Table 16.—*Moisture content of curds of different but fixed acidity.*

Time after cutting.	Moisture in curd.		
	Vat I, acidity 0.17 per cent.	Vat II, acidity 0.20 per cent.	Vat III, acidity 0.25 per cent.
Hrs. m.	*Per cent.*	*Per cent.*	*Per cent.*
0 0	87.0	87.0	87.0
0 30	82.4	81.3	79.6
1 0	74.5	72.5	67.1
1 30	72.2	69.0	64.2
2 0	70.7	67.1	62.9
3 0	68.8	65.2	58.6

Table 17.—*Acidity of whey in cheese of Table 16.*

Vat I.		Vat II.		Vat III.	
Time after cutting.	Acidity.	Time after cutting.	Acidity.	Time after cutting.	Acidity.
Hrs. m.	*Per cent.*	*Hrs. m.*	*Per cent.*	*Hrs. m.*	*Per cent.*
0 0	0.11	0 0	0.13	0 0	0.17
2 20	.12	2 20	.133	2 20	.174
5 15	.13	3 20	.138	3 20	.177
		4 13	.142	4 10	.177

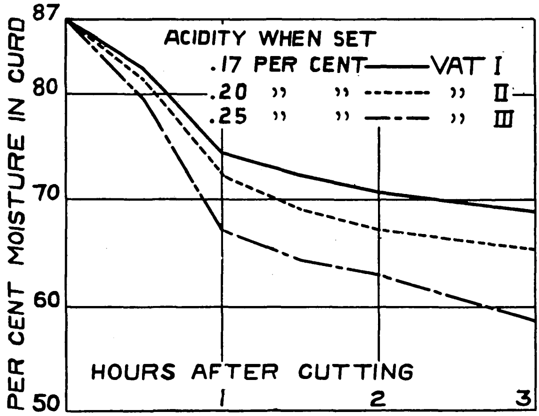

Fig. 14.—Effect of acidity on rate of separation of whey from curd. The milk was acidulated by adding hydrochloric acid. Increasing the acidity accelerated the whey separation.

These and other data show that moisture separates from curd more rapidly when the concentration of acid in solution in the whey within and around the curd is 0.17 per cent than when it is 0.13 or 0.11 per cent, and more rapidly at 0.13 per cent than at 0.11 per cent. Since there was practically no change in the acidity of the whey surrounding the curd, it is certain that the acidity within the curd remained at the observed figures during the period after cutting.

SEPARATION OF MOISTURE FROM RIPENED MILK CURD AT FIXED ACIDITIES.

In the following experiment the acidity of the milk was raised by ripening, not hydrochloric acid, to 0.177, 0.21, and 0.26 per cent, respectively, in the three vats. The milk was then heated to 150° in the vats by passing steam into the jackets, and cooled by filling the jackets with cold water, stirring all the time. After pasteurizing, each vat was set at 86° with 3 ounces of rennet per 1,000 pounds. The milk became visibly thickened in eleven, seven, and four minutes, respectively, and the curds were cut into ½-inch cubes twenty-nine, twenty-one, and eighteen minutes after adding rennet. The moisture content of the curds and the acidity of the wheys are shown in Tables 18 and 19. (See also fig. 15.)

TABLE 18.—*Moisture content of curds ripened to different degrees and pasteurized.*

Time after cutting.	Moisture in curd.		
	Vat I, acidity 0.177 per cent.	Vat II, acidity 0.21 per cent.	Vat III, acidity 0.26 per cent.
Hrs. m.	*Per cent.*	*Per cent.*	*Per cent.*
0 0	87.0	87.0	87.0
0 30	82.2	81.8	80.7
1 0	74.4	73.1	71.7
1 30	71.1	69.8	67.8
2 0	....	68.0	64.5
2 30	67.5	66.9	63.3

TABLE 19.—*Acidity of whey in cheese of Table 18.*

Vat I.		Vat II.		Vat III.	
Time after cutting.	Acidity.	Time after cutting.	Acidity.	Time after cutting.	Acidity.
Hrs. m.	*Per cent.*	*Hrs. m.*	*Per cent.*	*Hrs. m.*	*Per cent.*
0 0	0.125	0 0	0.14	0 0	0.18
0 55	.125	2 35	.142	....	....
2 5	.125	3 0	.153	2 30	.19
3 0	.137	....	....	....	....

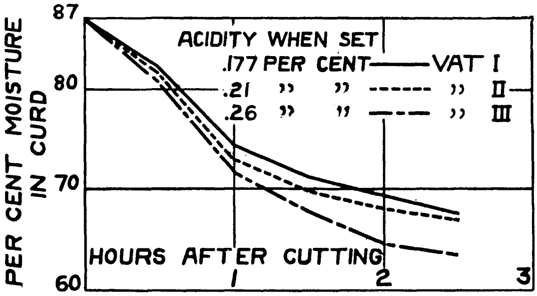

FIG. 15.—Effect of ripening milk to different degrees of acidity and then pasteurizing it before setting. The increase in the percentage of acid accelerated the rate of whey separation.

In this experiment the acidity of the surrounding whey was the same as the acidity of whey within the curd, since no increase of acidity occurred at any time after cutting the curd.

The curds with higher acid content gave up whey more rapidly than those of lower acidity. The moisture content fell more rapidly during the second half hour because the temperature was raised. After the first hour the moisture content decreased more slowly and did not go below 63 per cent in two and one-half hours after cutting.

SEPARATION OF MOISTURE FROM CURD OF VARYING ACIDITY.

In this experiment four vats of milk were used. One was set as soon as possible at 0.17 per cent acidity and 86°. The second was held at 86° for one hour before setting, and, although the acidity was 0.17 per cent when set, the acidity of the whey rose faster after cutting than in vat I. In vat III the milk was ripened to 0.185 per cent, and in vat IV to 0.20 per cent before adding rennet. The curds were not stirred on the rack and were handled exactly alike. The acidity of the wheys and the moisture content of the curds at various intervals are given in Tables 20 and 21, and the effect of setting the milk at different degrees of ripeness is shown in figure 16.

TABLE 20.—*Moisture content of curds with varying ripeness.*

Time after cutting.	Operation.	Moisture in curd.			
		Vat I.	Vat II.	Vat III.	Vat IV.
Hrs. m.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0 0	....	87.0	87.0	87.0	87.0
0 30	....	82.0	81.2	77.5	75.8
1 30	....	67.5	65.7	62.9	61.0
2 30	Dipped...	63.0	60.8	56.6	56.7
2 45	....	54.0	50.5	49.3	51.0
3 0	....	49.4	45.8	44.7	48.3
4 0	Milled.....	43.5	42.9	42.4	44.8
6 0	Salted.....	40.3	40.0	39.0	41.1
6 20	Hooped...	38.0	36.7	36.3	40.6

TABLE 21.—*Acidity of whey from curds of varying ripeness.*

Vat I.		Vat II.		Vat III.		Vat IV.	
Time after cutting.	Acidity.	Time after cutting.	Acidity.	Time after cutting.	Acidity.	Time after cutting.	Acidity.
Hrs. m.	*Per cent.*	*Hrs. min.*	*Per cent.*	*Hrs. min.*	*Per cent.*	*Hrs. min.*	*Per cent.*
0 6	0.114	0 3	0.115	0 8	0.125	0 6	0.142
0 36	.116	0 36	.122	0 50	.140	0 24	.150
1 33	.125	1 0	.130	1 13	.149	0 46	.167
1 58	.131	1 31	.140	1 47	.157	1 16	.175
2 30	.134	2 4	.150	2 8	.174	1 49	.217
				2 30	.180	2 30	.250

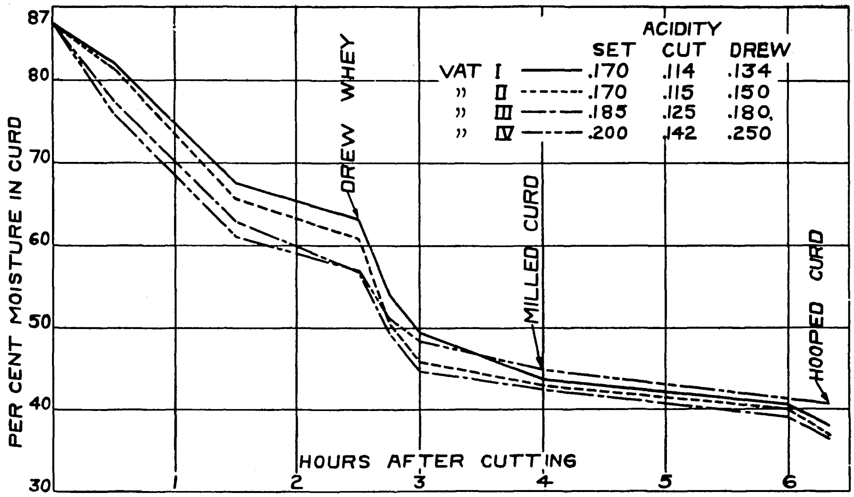

FIG. 16.—Effect of setting the milk at different degrees of ripeness. Curve IV is lower than curves I, II, and III at first, but crosses them between two and one-half and three and one-half hours after cutting and remains higher. This shows the characteristic tendency of high-acid curds to retain more moisture than curds of moderate acidity.

Where acidity is developing briskly in the curd, as in vat III, the moisture content of the curd falls readily to 58 per cent or less in two and one-half hours after cutting, but where there is little acid development, as in vat I, the moisture content falls more slowly.

The high proportion of acid in vat IV caused the curd to feel very soft at the time of dipping, though it had no more moisture at that time than the curd in vat III, which did not feel soft. The soft condition of curd in vat IV was probably due to the chemical influence of acid on the curd; it certainly was not due to excessive moisture.

The high-acid curd in vat IV lost moisture less rapidly on the rack than the others, so that when milled, salted, and hooped it had more moisture than those of medium acidity. This effect accompanied such high acidity in all cases.

In the preceding experiments the rate at which moisture separates from curd in the whey was shown to be more rapid at moderately high than at low acidity, but in this experiment it is seen that after the acidity of the whey passed above 0.18 per cent, as in vat IV, the rate of moisture separation was not proportionately increased. The curd in vat IV, when dipped at a whey acidity of 0.25 per cent, had no less a content of moisture than the curd in vat III, dipped at a whey acidity of 0.18 per cent.

Another similar experiment will be described in which the same effects produced by varying acidity can be seen. In this experiment four vats of milk were used. One was set at 0.16 per cent acidity, using no starter. The second was held at 86° for one hour and set at 0.17 per cent acidity. To the third 1 per cent of starter was added, and after ripening one and one-half hours it was set at 0.19 per cent. The fourth vat was ripened one and three-fourths hours with 2 per cent starter and set at 0.20 per cent. The acidity of the whey when drawn two and one-half hours after cutting was 0.13, 0.16, 0.21, and 0.27 per cent, respectively, in the four vats. The moisture content of the curds is given in Table 22. The curd in vat IV, set at 0.20 per cent and drawn at 0.27 per cent acidity, did not loose moisture any faster in the whey than vat III, which was set at 0.19 and drawn at 0.22 per cent acidity. (See fig. 17.)

TABLE 22.—*Moisture content of curds cut and firmed at various degrees of acidity.*

Operation.	Acidity.			
	Vat I.	Vat II.	Vat III.	Vat IV.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
When set........	0.16	0.17	0.19	0.20
When cut........	.105	.115	.127	.15
When drawn.....	.13	.16	.22	.27
Time after cutting.	Moisture.			
Hrs. m.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0 0	87.0	87.0	87.0	87.0
0 30	81.2	79.1	79.5	78.9
1 10	....	70.0	66.9	66.8
1 50	69.3	66.2	....	....
2 30	66.5	63.3	58.3	59.0

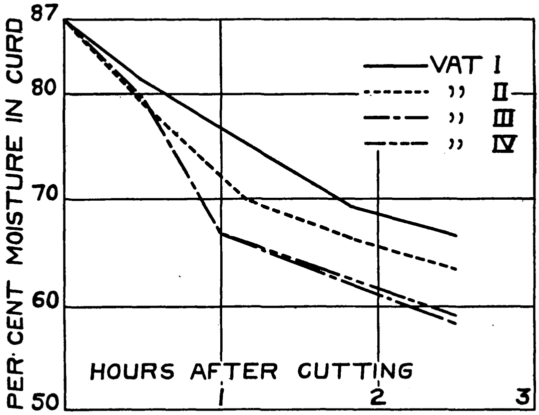

FIG. 17.—The same as figure 16, except that curd IV was riper.

In handling curds from overripe milk in a factory it should be remembered that when the whey acidity passes above 0.18 per cent the rate of separation of moisture from curd increases very little, if any, and there is little to be gained, as to firmness of curd, by prolonging the time that the curd remains in the whey. The very soft feeling which persists in a curd from overripe milk is often due to high acidity and not to excessive moisture.

THE USE OF UNRIPENED MILK IN CHEESE MAKING.

The system of setting milk for Cheddar cheese with rennet while very sweet and without starter has gone out of use.[a] The method nearest to it among those now practiced is to add starter and set the milk without ripening, or to set the vat without starter, fairly sweet, in the belief that acidity will develop rapidly. In either of these cases the development of acid may be slower than expected, and sometimes it does not begin before the curd has been an hour or more in the whey.

In cases where acidity is lacking after cutting, the moisture content decreases fairly rapidly down to about 65 per cent, or a little more or less according to the temperatures and size of cubes, but below this figure the decrease is very slow. If rapid formation of acid begins late in the process, an increase in the rate of moisture separation may be observed, as was the case in the experiment shown in Table 23 and figure 18. The increased rate of moisture separation is shown in the figure by the downward bend of the curve at the time when the acidity began to increase rapidly, three hours after cutting.

Table 23.—*Rate of separation of moisture from curd when rapid aevelopment of acid begins late in the process.*

Time after cutting.		Moisture content of curd.	Acid content of whey.
Hrs.	*m.*	*Per cent.*	*Per cent.*
0	0	87.0	
0	30	80.5	
0	48		0.115
1	0	73.8	
1	30	68.8	
2	0	66.7	
2	10		.128
2	30	65.2	
3	0	64.0	.137
3	30	62.4	.145
4	0	59.4	.155
4	30	56.9	.172

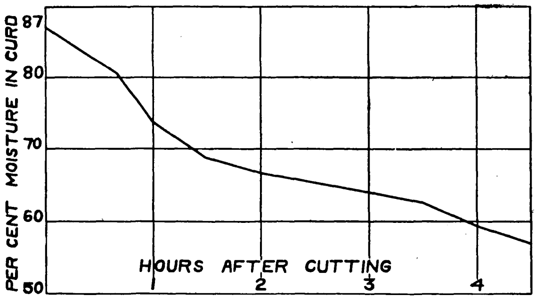

FIG. 18.—Showing increased rate of moisture separation due to rapid increase of acidity at late stage.

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[a] Arnold, L. B. American dairying. Rochester, N. Y., 1876. P. 327.

The figures show what takes place in a vat of milk in which little or no acid formation occurs immediately after cutting, such as is occasionally met with to-day, and also shows why the old-time cheese makers could leave a sweet-milk curd in the whey for a number of hours without getting an excessively dry cheese. In the absence of lactic acid, the removal of moisture from curd is automatically checked at about 65 per cent, and the effects of modifying the early steps of the process as to temperature and time and rate of heating the vat are practically obliterated in two hours after heating the vat. Examples of these are shown in tables 6 and 9.

The tenacity with which the remaining moisture is held is perhaps due to chemical attractions between the water and the other milk constituents. With the appearance of a new factor, lactic acid, whose presence introduces new attractions, the moisture readily falls to 50 or 55 per cent in the curd. At this point, again, the rate of moisture separation decreases, showing that, in general, the lower the moisture content falls the more tightly is the moisture held by the curd.

THE USE OF PARTLY RIPENED MILK FOR CHEESE MAKING.

The system of regulating acidity most commonly employed since starters and acid and rennet tests came into use consists in getting the acidity up to 0.17 or 0.19 per cent in the milk and observing that an increase of acidity is really occurring in the vat before adding rennet, so that the operator has reason to believe that acid formation will continue at a fairly rapid rate after cutting.

The conditions of acidity at present sought are described more in detail at the beginning of this bulletin, and under these conditions the moisture content of curd falls fairly rapidly to about 50 or 55 per cent, instead of practically stopping at 63 to 68 per cent, as occurs with unripened milk curds. As previously stated, it is the custom at present to have about 0.17 per cent of acid in the whey by the time the curd is firm, but a smaller development of acid will suffice to bring down the moisture content to 55 per cent in the curd. Therefore, to insure so far as possible that 0.17 per cent of acid, instead of 0.15 per cent, for example, is present in the whey by the time the curd is firm enough to dip without unnecessary loss of fat, the cheese maker has to judge for himself before adding rennet whether acidity is increasing at a suitable rate.

INFLUENCE OF PASTEURIZATION ON SEPARATION OF WHEY FROM CURD.

There is no question that pasteurization of the milk checks acid development in the curd. In addition, the heating of the milk may affect the constitution of the casein, or its relation to the water present, in such a way as to influence the ease and the rate of separating the whey. This point was tested in an experiment with three vats of milk. The milk in vat III was set at 0.17 per cent acidity, cut at 0.115 per cent, and three hours and fifteen minutes later the acidity had reached 0.135 per cent, showing that the rate of acid development was very slight. In vat II twice as much of the same lot of milk was placed and ripened with 1 per cent starter for two hours, which brought the acidity to 0.19 per cent. The acidity of the whey in vat II when cut was 0.14 per cent, and three hours and ten minutes later it was 0.24 per cent. Just before setting vat II, half of the milk was transferred from it to vat I and there heated rapidly to 150° and cooled. The heating required four minutes and the cooling twenty-five minutes. Each vat was set with 4 ounces of rennet per 1,000 pounds of milk at 86°, and the curds were cut, heated, and handled alike in all respects. The moisture content of the curd is shown in Table 24. (See also fig. 19.)

TABLE 24.—*Comparison of moisture content of curds from sweet, ripened, and pasteurized milk.*

Time after cutting.		Vat III, sweet milk.	Vat II, ripe milk.	Vat I, pasteurized milk.
Hrs.	*m.*	*Per cent.*	*Per cent.*	*Per cent.*
0	0	87.0	87.0	87.0
0	30	81.0	80.2	82.5
1	0	75.1	69.4	75.0
1	30	71.5	63.3	70.9
2	30	70.0	60.5	....
2	30	....	....	68.0
3	0	66.7	56.4	....
3	30	....	....	65.5
4	0	61.8	....	....

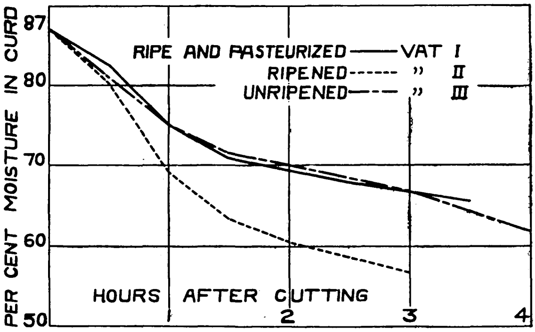

FIG. 19.—Effect of sweet, ripe, and ripe pasteurized milk on rate of moisture separation.

The milk in vat I, set at 0.19 per cent acidity, after pasteurizing gave up its whey at about the same rate as the sweet milk in vat III set at 0.17 per cent. There was a slight increase of whey acidity in vat III, but none in vat I. From this it appears that the rate at which moisture separates from curd when the milk is pasteurized is about the same as when the milk is sweet and practically uninoculated with bacteria.

Further study of the relation of pasteurization to cheese-making is in progress and will be reported later.

EFFECT OF PRESSURE ON MOISTURE CONTENT OF CURD.

It is generally supposed that pressure applied to the curd in the press does not drive moisture from the interior of the curd cubes, but removes only that which is on the surface. The following quotation from Decker[a] expresses the facts, so far as they could be observed in the course of ordinary factory work:

> The idea that we make a cheese dry by pressing it is an erroneous one. The whey must be removed from the curd while it is in the vat; if it is not, no amount of squeezing in the press will expel it.

While it is impossible to get a very moist curd dry and firm by ordinary squeezing in the press, yet a notable proportion of water is removed by pressure, as shown by the following experiment: Four curds were sampled just before hooping, by use of the sharp brass sampling tube. Two portions of each sample were placed in tin boxes and weighed. Two similar portions were carefully wiped, piece by piece, with filter paper, then placed in boxes and weighed. The filter paper removed all surface moisture. The next morning, as soon as the curds came out of the press, they were sampled again with an ordinary cheese trier at a point about halfway between the center and the edge. The samples were all dried in the oven at the same time. The results show that the loss by wiping is on the average 0.3 per cent and by pressing 4.1 per cent, and that about 3.8 per cent of moisture removed in the press was not superficial at the time of hooping.

TABLE 25.—*Loss of moisture caused by wiping and by pressing curds.*

Operation.	Moisture in curd.			
	Vat I.	Vat II.	Vat III.	Vat IV.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Sample as hooped	37. 4	37. 1	37. 9	38. 8
Sample after wiping	36. 8	37. 0	37. 8	38. 5
Sample after pressing	31. 7	33. 3	33. 9	34. 9

Exact moisture determinations show that pressure in the hoop does remove notable proportions of moisture held superficially and otherwise by the curd when hooped.

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[a] Loc. cit., p. 87.

Respecting the influence of pressure on curd in the vat Lloyd[a] wrote, in 1899, after describing methods used in England:

> The chief and characteristic difference between various methods of cheese making depends on the course taken to obtain the curd sufficiently dry. At this time, 1857, only two methods were known, the one by use of heat, the other by the use of pressure. The latter was the system of Joseph Harding, the curd being subjected to pressure in the vat before being finally ground and pressed into a cheese.

LOSS OF MOISTURE BY PRESSURE AFTER PUTTING CURD ON RACK.

In many of the experiments already described[b] it can be seen that during the first fifteen to thirty minutes after the curds were out of the whey and piled up without stirring the moisture content fell more rapidly than while they were in the whey. At this stage the superficial moisture drains away from the cubes, and a considerable amount of moisture which is not superficial, that is, which can not be removed by bibulous paper, is also driven out. Under the pressure of the piled curd the cubes at the bottom of the mass quickly lose their regular cubical shape and pack together, like figs in a box, so closely as to prevent the free drainage of whey through the bottom of the curd. The distorted, packed cubes coalesce more or less quickly, forming a single mass in which the boundaries of the separate cubes can not be distinguished. This entire process of packing and coalescing is called "matting" by the cheese maker. The middle layer of the mass mats more slowly, and the matting of the top layer is completed a few minutes later by turning the curd mass upside down, thus putting it under pressure.

The separation of whey from a single large mass of curd, such as an uncut curd, is exceedingly slow. It has already been shown that the smaller the pieces into which a curd is cut the more rapid is the rate of whey separation. The converse may be taken for granted, namely, that when the curd cubes coalesce to a single mass the separation of moisture is markedly checked. If the cause of the rapid loss of moisture on the rack is the pressure of curd particles on each other, then it should be possible to remove moisture from curd by application of pressure to the curd under the whey.

LOSS OF MOISTURE BY PRESSING THE CURD UNDER THE WHEY.

In the following experiment three vats of milk containing 200 pounds each were set at 0.16 per cent acidity, cut alike, and heated in thirty-five minutes to 104°. The whey in vat I was drawn two and one-half hours after cutting and the curd put on the rack in the usual manner, the whey acidity being 0.125 per cent. In vat II the curd and whey were scooped into a 15-inch Cheddar cheese hoop containing some curd cloth and set in the vat two hours after cutting. A circular board, the follower, was put on the curd, and a 25-pound weight placed on top. The follower was removed at intervals of four minutes, the curd being stirred up and sampled and then put under pressure again.

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[a] Loc. cit., p. 12.

[b] See figures 1, 3, 7, 9, 10, 11, 15.

A reduction of moisture content from 65.9 to 52.8 per cent was effected by this means in vat II in thirty minutes. During this time the curd in vat I had decreased from 65.3 to 63.9 per cent in moisture. As it would not be convenient to apply pressure in this manner to the curd in a large vat, an effort was made to reduce the moisture content of the curd in vat III by drawing off a large proportion of the whey two hours after cutting. The whey was left about 1 inch deep, and the curd stood 2 or more inches above the whey. By occasional stirring the curd was prevented from matting. The moisture content fell from 66.1 to 55.6 per cent in one-half hour, and the method seemed to be quite effective as a means of rapidly reducing the moisture content of a soft curd just before putting the curd on the rack. The details are shown in Table 26 and figure 20.

TABLE 26.—*Effect of pressure on moisture content of curd in the vat.*

Time after cutting.		Operation.	Moisture in curd.		
			Vat I (put on the rack in the usual manner).	Vat II (external pressure applied while curd was under the whey).	Vat III (whey mostly removed, leaving curd under its own pressure for half an hour before dipping).
Hrs.	*m.*		*Per cent.*	*Per cent.*	*Per cent.*
0	30	....	78.6	79.8	79.0
1	0	....	71.3	71.2	71.3
1	30	....	66.8	68.0	....
2	0	....	65.3	65.9	66.1
2	10	....	....	58.6	60.6
2	30	Dipped	63.9	52.8	55.6
4	0	Milled	41.7	40.6	41.5
5	0	Hooped	39.0	40.0	38.8

The only reference to such a method which the writer has been able to find in the literature is the following by Waddell and McKay,[a] who say in giving instructions for making cheese from overripe milk:

> Run off the whey as soon as possible and stir the curds well in the small amount of whey before dipping, so as to have the curds well firmed before sufficient acid is developed.

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[a] Waddell, W., and McKay, A. Hints on the care of milk for creameries and cheese factories, and Canadian Cheddar cheese making. In Dairy School Bulletin 143 of the Ontario Agricultural College and Experimental Farm, pp. 1–56. Toronto, 1905. See p. 34.

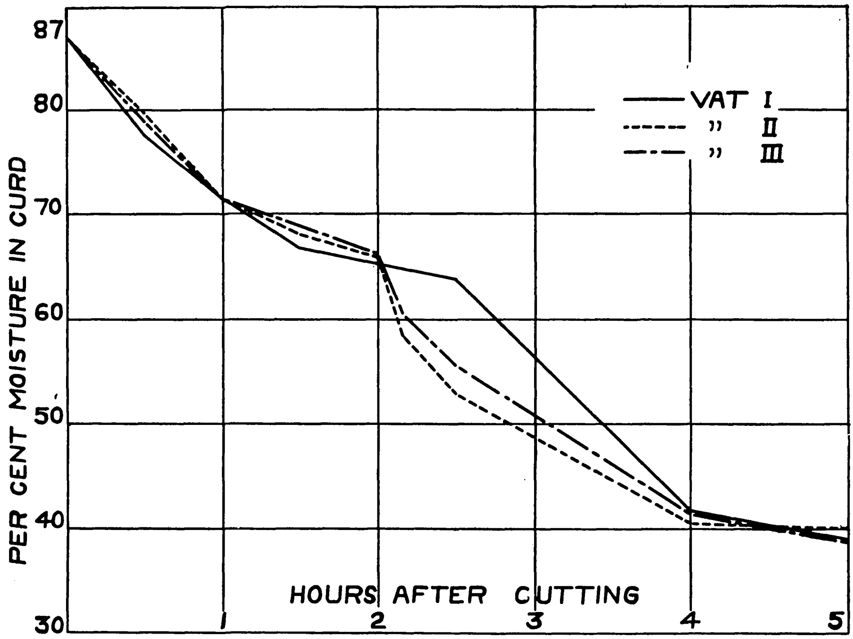

FIG. 20.—Effect of pressure on the moisture content of curd. Curves II and III show how the moisture content of a curd in the whey was reduced by applying external pressure for a few minutes. Compare with curve I, made without pressure.

These writers do not say how effective the method is in removing moisture, nor do they show that the level of the whey must go below the curd level to produce the desired result.

SELF-PRESSURE OF CURD IN THE WHEY—COMPARISON OF SHALLOW AND DEEP VATS.

Cheese makers often ask whether the pressure of curd particles on each other when allowed to settle in the whey is sufficient to drive out whey from the curd. The curd cubes while in the whey are buoyed up by the liquid to such an extent that they exert only a very slight pressure on each other at the bottom of the vat. The specific gravity of the curd is about 1.045 and of the whey 1.021 at the temperature of the vat; therefore a piece of curd weighing 1.045 grams in the air weighs $1.045 - 1.021$, or about 0.024 gram when under the whey, which is about one forty-third of its weight in air. Consequently it should not be expected that the pressure of curd particles on each other when allowed to settle under the whey would have much influence on the moisture content. The facts are shown by the following experiment:

Two vats were used, one containing 200 pounds of milk and one containing 600 pounds. The milk in the first stood 6 inches deep and in the other 18 inches. It tested 4 per cent fat and 0.175 per cent acidity, and was all taken from the same lot of mixed milk. The two vats had the same dimensions excepting in depth, and the milk in the vats was handled exactly alike in all respects. It was set with 4 ounces of rennet per 1,000 pounds at 86°. Each curd was cut into ½-inch cubes fifteen minutes after adding rennet. Fifteen minutes later steam was turned on and the vats were heated to 104° in twenty minutes. They were carefully maintained at this temperature and were sampled at thirty-minute intervals. After heating, the curds were stirred regularly at fifteen-minute intervals and allowed to settle between times. Under these circumstances the layer of whey and of curd in the second vat was as deep as commonly occurs in a factory vat, while that in the first vat was only one-third as deep. If the pressure of the curd particles on each other under the whey is an important factor in the separation of moisture from curd in ordinary cheese making, there should have been a noticeable difference between the moisture content of these two curds. There was, however, no difference, as is shown in Table 27.

TABLE 27.—*Moisture content of curds made in deep and shallow vats.*

Time after cutting.	Moisture in curd.	
	Vat I (milk 6 inches deep).	Vat II (milk 18 inches deep).
Hrs. m.	*Per cent.*	*Per cent.*
0 0	87.0	87.0
0 30	79.9	78.4
1 0	67.3	67.8
1 30	64.0	....
2 0	60.2	60.9
2 30	57.7	56.3

From this and similar experiments it was concluded that the pressure of curd particles on each other at the bottom of the cheese vat is not sufficient to hasten the removal of moisture from the curd. There was no difference between the results obtained with 200 pounds and with 600 pounds, and it seems reasonable to believe that the results obtained in small experimental vats would be obtained with any sized vat if handled in the same way.

EARLY REMOVAL OF PART OF WHEY FROM VAT.

Cheese makers often drain off a large proportion of the whey above the curd quite early in the process after cutting. The remainder of the whey being less in volume can then be removed more quickly when the curd is ready to mat.

In his work on "Canadian Dairying," Professor Dean[a] gives the following directions: "In summer, it is wise to remove most of the whey from the curd soon after heating in order to better control the development of acid."

The question has been asked whether the early removal of part of the whey from the vat has any influence on the rate at which the curd gives up moisture. To answer this question the following experiment was tried repeatedly with both sweet and ripened milk, and always with the same conclusion. Two vats of mixed milk testing 4 per cent fat and 0.180 per cent acidity were set at 86° with 4 ounces of rennet per 1,000 pounds. The curds were cut into ½-inch cubes twenty-five minutes later, and heat was applied to each fifteen minutes after cutting, reaching 104° twenty minutes later.

The vats were handled exactly alike in all respects excepting that a strainer was placed in vat I and a slow stream of whey was started by partly opening the gate twenty-four minutes after cutting. The whey was caught in buckets, and the weight and time of filling each bucket were recorded. Care was exercised to draw the whey no lower than the top of the curd, in order that the curd particles might always have the buoying effect of the surrounding liquid. The time of each operation, the weight of whey removed from vat I, the moisture content of the curds, and the acidity of the whey in each vat are given in Tables 28 and 29 and figure 21.

Table 28.—*Influence of early removal of part of whey from vat—Comparison of acidity.*

Time after cutting.	Whey removed from vat I.		Acidity of whey in vat I.	Acidity of whey in vat II.
	Total weight.	Proportion of vat contents.		
Hrs. m.	*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*
0 0			0.13	0.13
0 29	23	11.5		
0 34	45	22.5		.14
0 40			.14	
0 53	67	33.5		
1 5			.155	.152
1 15	89.5	44.75	.165	
1 25				.161
1 30			.172	
1 45			.20	
1 50	104	52		
2 0				.177
2 5			.215	
2 20				.197
2 25			.237	
2 30			.260	.200

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[a] P. 165.

Table 29.—*Influence of early removal of part of whey from vat—Comparison of moisture content of curd.*

Time after cutting.	Operation.	Moisture in curd.	
		Vat I.	Vat II.
Hrs. m.		*Per cent.*	*Per cent.*
0 30	....	79.4	78.6
1 0	....	68.1	69.3
1 30	....	64.6	....
1 40	....	....	61.9
2 30	Dipped...	56.5	55.2
3 0	....	45.7	44.1
4 0	Milled	42.8	41.5
6 0	Salted	39.0	38.8
6 20	Hooped...	36.4	36.5

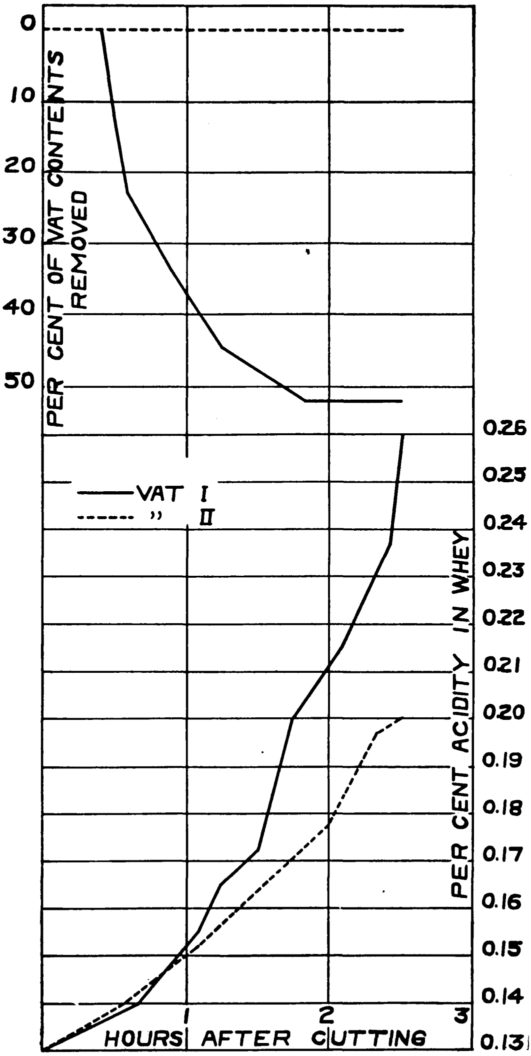

Fig. 21.—Effect of removal of whey on acidity.

No starter was used. The milk was well mixed before use and the vats were handled alike, so that it is certain that the amounts of acid formed by the bacteria in the two vats were alike. The acidity of the whey in vat I rose to 0.26 per cent in the same length of time that it rose to 0.20 per cent in vat II because the volume of whey in vat I was reduced to less than half the volume in vat II. The moisture content of the two curds was practically identical throughout.

From this and similar experiments it is concluded that the rate of separation of moisture from the curd is not affected by early removal of part of the whey from the vat if the curd is kept covered with whey. Where the acidity is developing rapidly in the curd and acid is passing from the curd into the whey, the acidity of whey in the vat increases more rapidly after a portion is drawn off than if none is removed. The smaller the bulk of whey surrounding the curd the higher its percentage of acidity will be raised by the transfer of a given weight of lactic acid from curd to whey. Therefore a cheese maker who relies upon the titration of whey with a standard alkaline solution for an indication of the acid development in the curd is likely to be misled and to imagine that the acidity of the curd is higher than it really is, if he has drawn off a considerable proportion of the whey early in the process and is titrating what is left in the vat. The later in the process the whey is drawn down the less important this source of error becomes, and where the whey gate is large, or where both siphon and whey gate are used, the whey need not be drawn down early and no such mistake need occur.

STIRRING THE CURD ON THE RACK.

It is the regular custom in many factories to stir the curd after piling it on the rack or on the bottom of the vat. Stirring prevents the curd cubes from packing together and permits them to drain longer and more completely before coalescing. It may be that the kneading and rubbing which the curd receives during the process of stirring on the rack hastens the loss of moisture, as additional pressure would do. The effect of stirring is especially marked where curds when dipped are soft and weak, from either excessive moisture or excessive acid, or other cause, so that they tend to mat rapidly and stop draining if not stirred.

On the rack the moisture content of curds falls rapidly at first, but afterwards the fall rapidly decreases. Below 45 per cent it falls very slowly, and it is very difficult by stirring for any length of time to reduce it below 35 per cent. The curd holds this proportion of moisture with great tenacity.

EFFECT OF STIRRING ON CURDS OF EQUAL ACIDITY BUT VARYING MOISTURE CONTENT.

Whatever be the stage of the process of firming in the whey when the curd is put on the rack, its moisture content can be quickly reduced by stirring, as is shown in the following experiment: Four vats of milk of 0.185 per cent acidity and 4.1 per cent fat content were heated to 86°, ten minutes apart, and were set one-half hour apart. The wheys were drawn ten minutes apart, when the curds had been in the whey one, one and one-half, two, and two and one-half hours, respectively, and contained 56 to 63 per cent water. The curds were put on the rack in each case three hours from the time the milk was heated. This was done in order that the four vats might be equally ripened at this stage. The whey acidity was 0.20 per cent. Each curd was stirred for eight minutes after it started on the rack. By stirring, the moisture content was reduced within half an hour after drawing to between 41.2 and 43.5 per cent in each of the curds. It appears from this that between one and two and one-half hours after cutting the whey can be drawn at any time when acidity or other conditions make it desirable, and the moisture content can be properly reduced by stirring on the rack. (See Table 30 and fig. 22.)

TABLE 30.—*Effect of stirring on curds of equal acidity but varying moisture content when dipped.*

Time after cutting.	Moisture in curd.			
	Vat I (cut to draw 2½ hours).	Vat II (cut to draw 2 hours).	Vat III (cut to draw 1½ hours).	Vat IV (cut to draw 1 hour).
Hrs. m.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0 30	78.0	78.2	76.6	76.4
1 0	....	64.5	64.1	[a] 62.4
1 10	65.2	....	....	....
1 30	....	60.0	[a] 60.0	43.1
1 50	59.5	....	....	....
2 0	....	[a] 58.0	43.1	42.7
2 30	[a] 56.8	42.7	....	....
3 0	43.5	....	41.2	41.2
3 30	....	40.6	40.4	[b] 38.8
4 0	39.8	39.7	[b] 37.9	....
4 30	39.0	[b] 37.1	....	....
5 0	[b] 37.4	....		....

[a] Sample taken just before drawing whey.
[b] Sample taken when the curd was hooped.

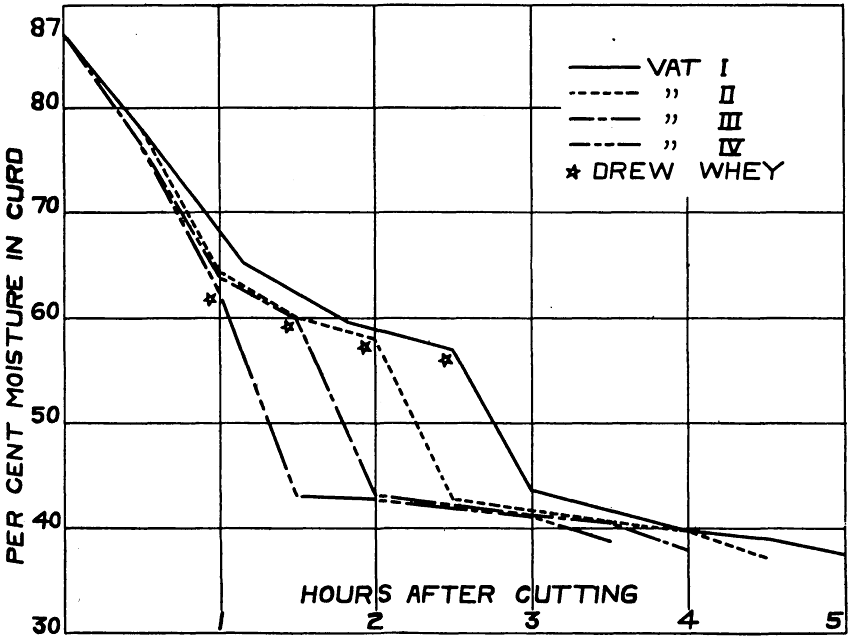

FIG. 22.—Effect on moisture of different times for dipping.

This experiment illustrates the fact that by stirring about eight minutes on the rack the moisture content of curds of equal acidity but of moisture content varying from 56 to 63 per cent can all be brought finally to the same figure. The moisture content when hooped depends very little on the moisture content just before dipping, if such curds are well stirred on the rack.

EFFECT OF STIRRING CURDS OF DIFFERENT ACIDITY.

In another experiment four vats of milk of 0.185 per cent acidity and 4 per cent fat were heated to 86° and set ten minutes apart. The whey was drawn one, one and one-half, two, and two and one-half hours, respectively, after cutting, when the acidity was 0.162, 0.17, 0.18, and 0.20 per cent. The curds were stirred eight minutes on the racks and were handled alike in all other respects. The moisture content of the curds varied from 56 to 67 per cent just before drawing the whey, and when hooped varied from 35 to 39 per cent. The curd of lowest acidity, when dipped, retained the most moisture after stirring and when hooped.

The conditions were precisely the same as in the last experiment described excepting that in the present instance both the acidity and the moisture content varied when the whey was drawn, while in the other case the acidity was alike in all four vats and the moisture varied when dipped. In consequence, when the curds were hooped the moisture varied in the present experiment, but not in the previous one. When hooped, the moisture content of a curd which was well stirred on the rack is independent of the moisture content when dipped, but is influenced to a notable degree by the acidity, curds of low acidity retaining more moisture than those of moderately high acidity. It has already been shown that curds of low acidity lose moisture while in the whey more slowly than curds of moderately high acidity. (See Table 31 and fig. 23.)

TABLE 31.—*Effect of stirring on moisture content of curds of varying acidity and moisture content.*

Time after cutting.	Moisture in curd.			
	Vat I (cut to draw 2½ hours).	Vat II (cut to draw 2 hours).	Vat III (cut to draw 1½ hours).	Vat IV (cut to draw 1 hour).
Hrs. m.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0 30	77.9	78.8	78.7	77.8
1 0	....	68.8	69.8	[a] 67.0
1 15	....	....	....	48.0
1 30	63.3	....	[a] 61.2	45.3
1 45	....	....	48.1	....
2 0	....	[a] 58.9	42.8	....
2 15	....	47.5	....	....
2 30	[a] 56.6	43.2	....	41.5
2 45	47.1	....	....	....
3 0	43.0	....	39.2	39.2
3 30	....	39.0	40.0	[b] 39.3
4 0	38.9	38.8	[b] 36.9	....
4 30	38.7	[b] 36.2	....	....
5 0	[b] 35.0	....	....	....

[a] Sample taken just before drawing the whey.
[b] Sample taken when the curd was hooped.

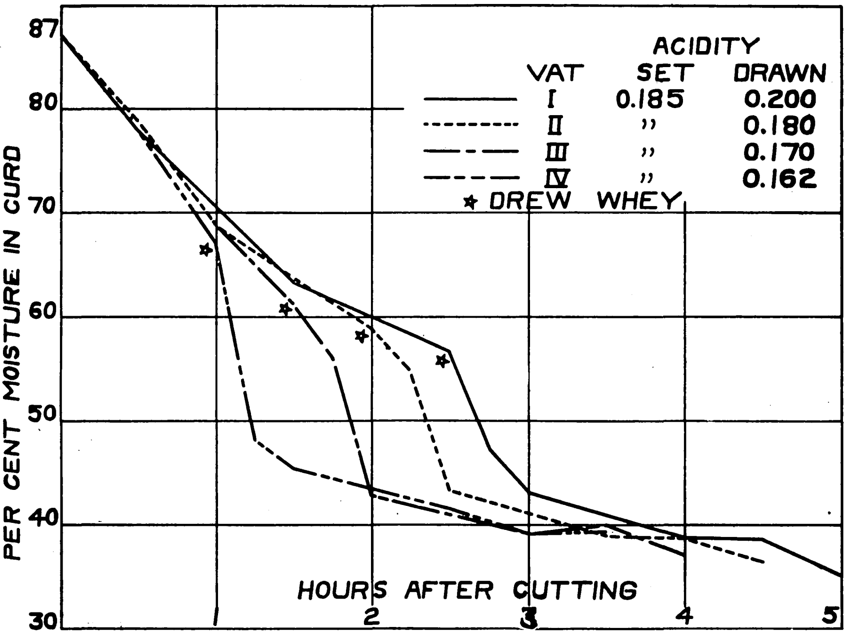

FIG. 23.—Effect of stirring the curd on the racks. Curds of unequal acidity when dipped are not brought to the same moisture content by stirring on the rack.

INFLUENCE OF FAT CONTENT OF CURD ON MOISTURE SEPARATION.

To determine whether curd gives up water more or less rapidly when the fat content is varied, several experiments were performed in the following manner: Eleven hundred pounds of whole milk of 0.165 per cent acidity and 4.3 per cent fat was collected in one vat and enough of it was run through a cream separator to furnish 400 pounds of skim milk, which was placed in another vat and mixed thoroughly. Portions of the skim milk and the whole milk were then weighed into the experimental vats, as indicated in Table 32. The vats were all heated to 86° and set with 3 ounces of rennet per 1,000 pounds. The curds were cut into one-half inch cubes and were heated in a uniform manner, beginning fifteen minutes after cutting, and reaching 104° twenty minutes later. The curds were sampled at intervals and moisture determinations were made on the samples as shown in Table 32 and figure 24.

TABLE 32.—*Moisture in curds containing different proportions of fat.*

Content.	Vat I.	Vat II.	Vat III.	Vat IV.
Whole milk.......pounds..	200	133	67	None.
Skim milk...........do....	None.	67	133	200
Fat determined..per cent..	4.3	3.0	1.7	0.07
Time after cutting.	Moisture in curd—			
Hrs. *m.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0 30....................	82.6	82.4	83.5	87.8
1 0....................	72.5	75.8	80.1	81.8
1 30....................	69.7	72.0	75.6	79.3
2 0....................	66.7	70.3	73.7	78.8
2 30....................	64.2	68.1	71.8	76.1

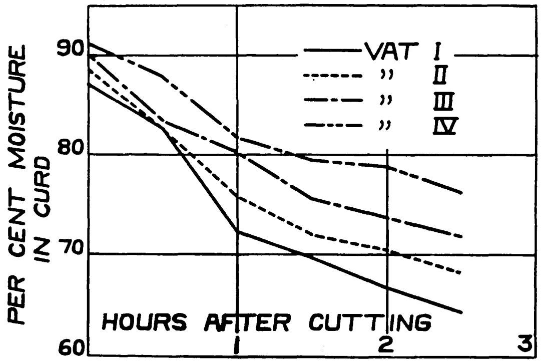

FIG. 24.—Effect of varying the fat content of the milk used.

It appears from the figures that the moisture content of curd I, containing the largest proportion of fat, fell to 64.2 per cent, while that in vat IV only fell to 76.1 per cent. In this form, however, the results are not strictly comparable, since the figure representing the percentage of moisture in vat I depends not only upon the moisture present but also upon the proportion of fat. The larger the proportion of fat present, the smaller the proportion of moisture will appear. In order to make the results comparable they should all be calculated to a fat-free basis. In order that this might be done, parts of the curd samples taken for moisture determinations were used also for duplicate fat determinations by the Babcock test.

The percentage of moisture in the curd divided by 1 minus the per cent of fat in the curd gives the percentage of moisture in the fat-free curd. The percentages of fat in the curd and of moisture in the fat-free curd are given in Table 33 and figure 25.

TABLE 33.—*Fat content of curds and moisture content of fat-free curds.*

Time after cutting.	Fat content.			
	Vat I.	Vat II.	Vat III.	Vat IV.
Hrs. m.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1 30	18.8	14.4	9.72	....
2 00	21.3	16.0	10.9	....
2 30	21.5	15.9	10.3	1.2
	Moisture in fat-free curd.			
1 30	85.8	84.1	83.7	80.2
2 00	84.7	83.7	82.1	79.7
2 30	81.8	80.9	80.0	77.0

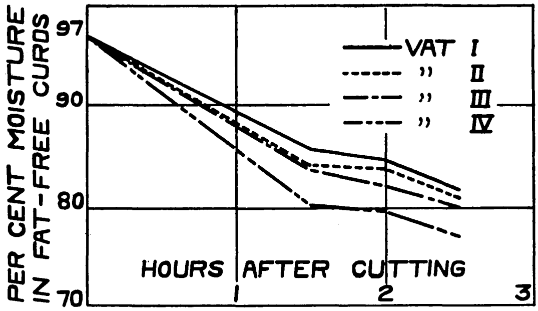

FIG. 25.—Effect of presence of fat on the moisture content of curds reduced to a fat-free basis. The presence of fat slightly delays the separation of moisture from the curd. Within natural limits of variation of fat content in herd milk, the effect is very small, as shown by vats I and II.

In this form the results show clearly that the moisture is removed more rapidly from the curds with the smaller content of fat. The fat by its presence somewhat delays the separation of moisture from casein. The same conclusion was reached by a different method, based on the weight of the green cheese obtained in the different vats and the ratio of moisture to casein in each cheese. The moisture was determined by the usual method in plugs drawn after the cheese had been taken from the press and weighed. The weight of water in the cheese is obtained by multiplication of the weight of cheese by the percentage of moisture. The weight of casein in each cheese is calculated in the following manner: In vat I the whole milk contained 4.3 per cent fat, and the casein calculated by Van Slyke's formula (no direct casein determination having been made) is 2.62 per cent. There was, therefore, about 8.6 pounds fat and 5.24 pounds casein in vat I and in the cheese made therein. Vat II contained 3.1 per cent fat, or 6.2 pounds, which is 2.4 pounds less fat than vat I. As all of the vats contained the same weight—200 pounds of milk—vat II consequently contained 2.4 pounds more of fat-free liquid than vat I. About 2.62 per cent, or 0.06 pound casein, is present in 2.4 pounds of milk, and therefore the casein content of vat II was 5.24 + 0.06 = 5.30 pounds.

In a similar manner the weight of casein in vats II, III, and IV are found to be 5.30, 5.37, and 5.46 pounds, respectively.

TABLE 34.—*Casein and moisture content of green cheese.*

	Vat I.	Vat II.	Vat III.	Vat IV.
Fat in milk .... per cent.	4.3	3.0	1.7	0.07
Weight of green cheese .... pounds	21.2	18.5	15.7	13.0
Moisture found .... per cent	37.4	41.2	45.0	51.7
Water present .... pounds.	7.93	7.62	7.06	6.72
Casein present .... do....	5.24	5.30	5.37	5.46
Water per pound of casein .... do....	1.51	1.44	1.31	1.23

Since the ratio of moisture to casein was the same in the four curds when cut and is found to be greatest, after pressing, in the green cheese containing the most fat, it follows that the separation of moisture from the curd has been delayed by the presence of fat.

Curd I had lost a smaller proportion of its moisture and therefore felt softer when grasped in the hand than the other curds. It contained more fat than the others, which also tended to make it feel softer. Although the milk was all taken from the same vat just before the experiment, it was found that the acidity of the whey when drawn was not quite uniform in the four vats. In this experiment the whey acidity was 0.13, 0.127, 0.125, and 0.12 per cent, respectively, in vats I, II, III, and IV, two and one-half hours after cutting. The effect of the slightly greater acidity in vat I would be to hasten slightly the separation of moisture from the curd in this vat, but this effect was entirely masked by the presence of the fat, which delayed the moisture separation to a greater degree.

INFLUENCE OF VARIATIONS IN THE PROPORTION OF CASEIN IN THE CURD.

In order to vary the casein content while retaining practically uniform fat content, separator skim milk containing 0.05 per cent of fat was mixed with different proportions of distilled water in the different vats. Vat I contained 200 pounds of milk, vat II contained 183 pounds of milk and 17 pounds of water, vat III contained 167 pounds of milk and 33 pounds of water, and vat IV contained 150 pounds of milk and 50 pounds of water. The casein varied as the numbers 1, 0.91, 0.83, and 0.75 in the four vats. The liquids began to thicken fourteen, sixteen and one-half, nineteen, and twenty-one and one-half minutes after adding 4 ounces of rennet per 1,000 pounds at 86°.

The curds were cut one hour and twenty-five minutes after adding rennet, at which time curd IV was not very stiff and did not seem to be improving.

Comparing vats I and IV as to content of water and solids, it is evident that the latter contained 50 pounds of water in place of 50 pounds of milk in vat I. The 50 pounds of milk in vat I contained about 6 pounds of milk solids, which was replaced in vat IV with 6 pounds of water. Therefore the water content of vat IV was about 6 pounds (or 3 per cent) greater than that of vat I.

The water content of vat I, when set, was about 90 per cent, while that of vat IV was 93 per cent, and vats II and III lay between these figures. Starting with these small differences of moisture content, the curds with the largest moisture content gave up moisture slightly more rapidly during the first hour, after which there was practically no difference in the percentage of moisture contained in the four curds, as shown in Table 35.

TABLE 35.—*Influence of variations in casein content on rate of moisture separation.*

Time after cutting.	Moisture in curd.			
	Vat I. (Milk, 200 lbs.; water, 0 lbs.)	Vat II. (Milk, 183 lbs.; water, 17 lbs.)	Vat III. (Milk, 167 lbs.; water, 33 lbs.)	Vat IV. (Milk, 150 lbs.; water, 50 lbs.)
Hrs. m.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0 40	86.0	85.6	86.4	85.0
1 0	81.8	82.1	81.2	82.5
1 30	79.0	79.1	79.5	79.2
2 0	76.0	76.9	76.7	76.2
2 30	75.0	74.8	76.1	74.5

The casein content of vat IV was three-fourths that of vat I, so that the ratio of moisture to casein was one and one-third times as great in curd IV as in curd I when cut, but this difference had entirely disappeared one hour after cutting. Increase in the ratio of moisture to casein in milk produces corresponding increase in the initial rate of moisture separation after cutting, thus tending always to produce curds of uniform relative proportions of moisture and casein.

EFFECT OF DILUTING MILK WITH WATER ON SEPARATION OF MOISTURE FROM CURD.

The natural variations of water content in milk may be simulated by adding proper proportions of water to normal milk. The effect of the addition of water upon the rate of moisture separation from curd is shown in the following experiment:

In order to maintain constant acidity, 1,100 pounds of whole milk containing 3.9 per cent fat and 2.85 per cent casein and of acidity 0.172 per cent was pasteurized at 150° in the Farrington duplex pasteurizer. After mixing the product thoroughly, 200 pounds were placed in vat I, 190 pounds with 10 pounds of distilled water in vat II, and 170 pounds with 30 pounds of water in vat III. Thus, vat II contained about 1.3 pounds and vat III about 4 pounds more water than vat I. The fat in vats II and III was, respectively, 3.7 and 3.3 per cent. The vats were heated to 86° and set with 4 ounces of rennet per 1,000 pounds. They were top stirred and cut, and were heated to 104° in thirty-five minutes and handled exactly alike in all respects. The moisture content of each curd is shown in Table 36.

TABLE 36.—*Separation of moisture from curd made from normal and from diluted milk.*

Time after cutting.	Moisture in curd.		
	Vat I. (Milk, 200 lbs.)	Vat II. (Milk, 190 lbs.; water, 10 lbs.)	Vat III. (Milk, 170 lbs.; water, 30 lbs.)
Hrs. m.	*Per cent.*	*Per cent.*	*Per cent.*
0 30	81.7	81.5	84.0
1 0	74.1	75.0	77.5
1 30	73.1	72.5	73.7
2 0	70.5	70.5	71.7
2 30	68.9	69.0	70.3
3 0	67.2	67.7	68.2

Vat III contained about 4 pounds more water and less milk solids than vat I, but the curd in vat III lost moisture more rapidly than that in vat I, and in one and one-half hours after cutting the percentage of moisture content of the three curds was practically identical. The addition of 30 pounds of water to 170 pounds of milk does not notably increase the moisture content of the resulting curds. The addition of water decreases the percentage of fat, also the ratio of casein to water, but does not affect the ratio of acid to casein in the vat. It has been shown above that such variations in the percentage of fat and in the ratio of casein to water have only a very slight influence on the moisture content of the resulting curd. Although the acidity of milk is decreased by adding pure water, the ratio of acid to casein is not affected and the final moisture content of the curd is not affected by such dilution. The most marked effect produced by adding water to milk is the increased time required for coagulation with rennet before the curd can be cut.

RATE OF MOISTURE SEPARATION FROM CURD AT VARIOUS STAGES AFTER CUTTING.

The moisture content of curds held at fixed temperatures from setting to dipping has been given in a previous experiment (see Table 4, p. 15). The weight, per 100 pounds of milk, of whey separated from the curd during successive time periods, as in vat I of the experiment referred to, can be calculated, as is shown in Table 37. For example, thirty minutes after cutting (column 1, Table 4), the curd contained 83.1 per cent moisture. As whey contains about 5 per cent of solids, the percentage of whey present may be represented by 1.05 times 83.1 per cent, or 87.2 per cent (column 3). The remaining 12.7 per cent of the curd is fat and casein, of which 100 pounds of milk contains 8.7 pounds. The fat and casein were determined respectively by the Babcock and the Hart methods. The weight of the curd was $\frac{8.7}{0.127}$ or 68.5 pounds. The weight of whey in the curd was $8.7 \times \frac{87.2}{12.7} = 59.3$ pounds (column 5). The weight of whey expelled from the cubes was $91.3 - 59.3 = 32$ pounds (column 6).

TABLE 37.—*Distribution of milk constituents between (a) curd cubes and (b) whey surrounding the cubes.*

Time after cutting curd.	Water found in curd by analysis.	Whey present in curd (calculated).	(a) Curd cubes contain—		(b) Whey above curd contains water, sugar, etc.
			Fat and casein.	Water, sugar, etc.	
Hrs. m.	*Per cent.*	*Per cent.*	*Pounds.*	*Pounds.*	*Pounds.*
0 0	87.0	91.3	8.7	91.3	0.0
0 30	83.1	87.2	8.7	59.3	32.0
1 30	77.8	81.7	8.7	38.8	52.5
2 30	73.0	76.6	8.7	28.5	62.8
2 45	64.3	67.5	8.7	18.3	73.0
3 0	60.5	63.5	8.7	15.1	76.2
4 0	53.9	56.6	8.7	11.3	80.0
6 0	43.4	45.5	8.7	7.3	84.0
6 20	39.8	41.8	8.7	5.4	85.9

It is clear that in this case the weight of whey separated from the curd during the first half hour was greater than during any subsequent similar period. (See fig. 26.) It may be questioned whether, other things being equal, the rate of separation of whey from curd at any time is proportional to the whey content of the curd at that time. To determine this, calculate, as in Table 38, the average weight of whey present in the cubes (column 3) during each of the time periods, and the average of loss of whey per minute (column 4) in each period. Dividing *b* by *a* gives the loss of whey per minute per pound of whey present in the cube, as shown in the last column. (See fig. 27.)

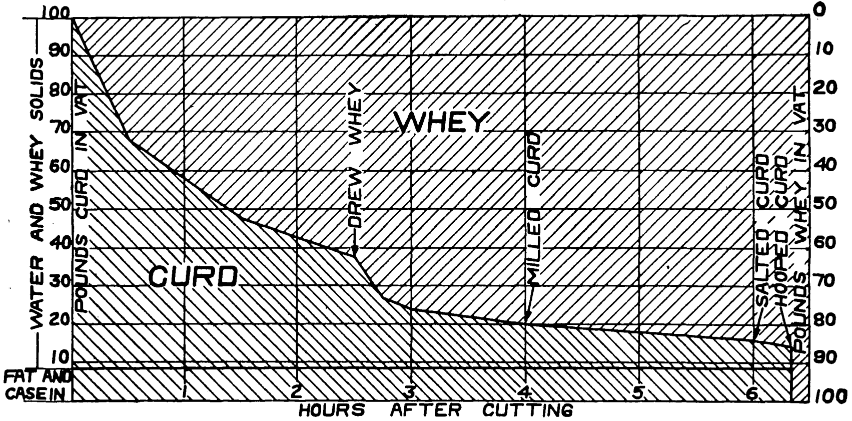

FIG. 26.—Showing the proportions of curd and whey in the vat at different stages of cheese making. Note that the rate of whey separation is accelerated at cutting, dipping, and salting.

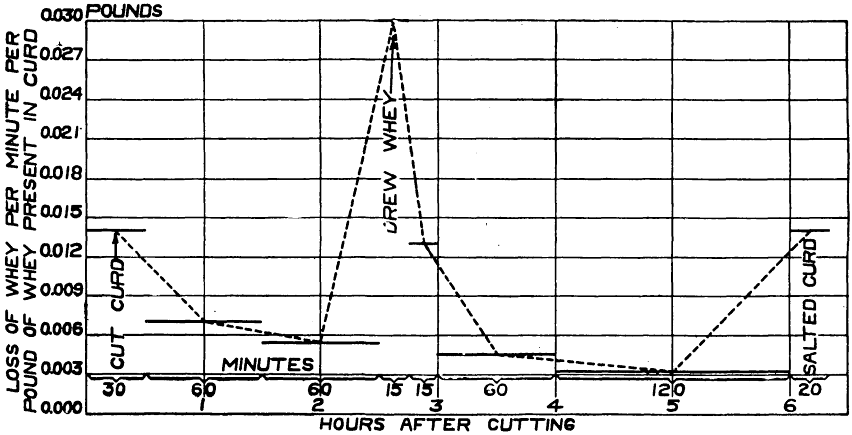

FIG. 27.—Showing the rate of loss of whey at various stages of the process. The loss occurs most rapidly at the points when the curd is cut, dipped, and salted.

TABLE 38.—*Loss of whey from curd per minute per pound of whey present in curd.*

Time after cutting.	Length of period.	(*a*) Average weight of whey in curd cubes during period.	(*b*) Average loss per minute of whey from curd.	Loss per minute per pound of whey present.
Hrs. m.	*Hrs. m.*	*Pounds.*	*Pounds.*	*Pounds.*
0 30	0 30	75.0	1.06	0.014
1 30	1 0	49.0	.34	.007
2 30 (Drew whey.)	1 0	33.6	.18	.0054
2 45	0 15	23.4	.70	.030
3 0	0 15	16.7	.21	.013
4 0 (Milled.)	1 0	13.2	.06	.0045
6 0 (Salted.)	2 0	9.3	.03	.0032
6 20 (Hooped.)	0 20	6.3	.09	.014

The loss of whey during any short period of time is not proportional to the whey content of the curd at that time. The amount lost per minute decreases much more rapidly than the whey content of the curd, showing that the less the whey content is the more tightly it is held to the curd.

The loss of moisture is more rapid during the first half hour after cutting than at any subsequent period while the curd is in the whey. The loss of moisture per minute which occurs when the curd is first put on the rack is greater in proportion to the actual moisture content of the curd than at any other period in the process. Immediately after cutting, drawing, and salting the rate of whey separation is accelerated, but rapidly falls off as time passes.

INFLUENCE OF THE HAND RAKE AS COMPARED WITH MECHANICAL AGITATORS.

The statement has been made by cheese makers that stirring a curd in a large vat with a hand rake causes more rapid firming than the use of mechanical agitators. If this is true, the difference may be due to greater pressure applied to the curd by the rake than by the agitator, since with the rake the curd must be repeatedly stirred up from the bottom, where it has settled, while with the agitator little settling occurs. It may be also that the use of the rake breaks up curd cubes somewhat more than the agitator; in which case, of course, the smaller pieces would lose moisture faster.

Other similar questions have arisen, but their consideration will be taken up later. Many practical questions respecting the combined influence of a given set of conditions can be answered from a study of the experiments already described.

CONCLUSIONS.

1. Variations in the proportion of rennet between 2 and 6 ounces per 1,000 pounds of milk do not influence the rate at which whey separates from curd in the cheese vat.

2. The action of rennet on milk curd for a longer or shorter period before cutting, or the relative softness or hardness of the curd when cut, does not influence the rate at which whey separates from curd.

3. During ripening the acidity of whey within curd cubes rises much faster and higher than that of the whey surrounding the cubes, because the principal seat of acid formation in the cheese vat is in the curd; whey gains most of its acidity from the curd.

4. The withdrawal of part of the whey from the vat soon after cutting does not affect the rate of separation of whey from curd, but the remaining whey rises more rapidly in acidity as a result of such withdrawal.

5. Curds made from very sweet or from overripe milk retain a larger proportion of moisture than curds from milk of medium ripeness.

6. Four curds cut with ¼, ⅜, ½, and ¾ inch curd knives, respectively, contained 49.7, 52.9, 58.2, and 69.8 per cent of moisture two and one-half hours after cutting, showing how great differences of moisture content are produced by using different knives.

7. Four curds set at 86° but heated thirty-five minutes after cutting to 86°, 92°, 98°, and 104°, respectively, contained 73.6, 63.7, 62, and 57.9 per cent of moisture two and one-half hours after cutting, showing that higher temperature facilitates the separation of whey.

8. Curds from sweet milk set at 86°, 92°, 98°, and 104° and all heated to 104° thirty-five minutes after cutting, differed in moisture content at first, but were alike after 1 hour. When ripe milk is used, one and one-half to two and one-half hours is required to reach the same end.

9. High acidity and high temperature induce rapid separation of the whey immediately after cutting. If the surface layers of the cubes are dehydrated by too rapid initial whey separation, so as to form a skin covering an interior pulp, the subsequent separation of whey is delayed. The yield of cheese is decreased, due to an excessive loss of fat through the broken curd walls, when such curds are taken out of the whey. Curds from overripe milk should be heated later and more slowly after cutting than curds from sweet milk, in order to avoid the skin-and-pulp condition, to insure complete removal of whey, and to avoid unnecessary loss of fat.

10. Pressure applied to curd in the press, on the rack, or under the whey hastens the separation of whey. On account of the buoying effect of the surrounding whey, the pressure of curd cubes on each other when allowed to settle under the whey is too slight to hasten the separation of moisture from curd. If the whey be mostly removed from the vat one-half hour before matting, so as to leave the curd under the pressure due to its own weight, whey is rapidly expelled. A little whey left in the bottom of the vat at this time helps to prevent matting.

11. When curd is piled on the rack its weight is great enough to expel moisture at an increased rate, until the moisture content reaches about 38 per cent, or until the process is stopped by matting. Stirring a curd on the rack prevents matting. When a curd is well stirred its final moisture content depends to a great extent on its acidity.

12. Variations in the fat content of milk, within ordinary limits, influence only very slightly the rate at which whey separates from curd, the presence of more fat tending to retard the process.

13. Variations in the percentage of casein or water in milk within ordinary limits have corresponding influence on the rate of moisture separation, the tendency being always toward the production of cheese with uniform moisture content. The addition of water to milk does not increase the moisture content of the resulting cheese, as the curd from watered milk gives up moisture more rapidly after cutting.

14. The loss of moisture immediately after cutting is rapid, but decreases in speed as time passes. The rate is increased when the curd is taken out of the whey and piled. After this it is rapidly decreased and is again increased when the curd is salted. The loss of moisture, per pound of moisture in the curd, is greatest at the time the curd is taken out of the whey and piled.

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